A&G

News and Reviews in Astronomy & Geophysics
April 2013 • Vol. 54 • Issue 2

Autumn MIST
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Gas giants and icy moons

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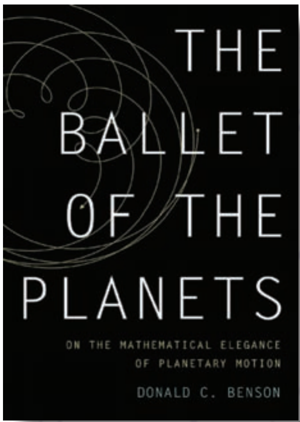


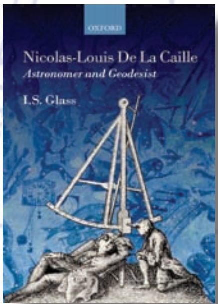
The Ballet of the Planets

A Mathematician's Musings on the Elegance of Planetary Motion

Donald Benson

The Ballet of the Planets unravels the beautiful mystery of planetary motion. The book shows how our understanding of planetary motion evolved from ancient Greece to the time of Newton. It illustrates the interaction between theory and observation, the scientific method, a process still central to the science of today.

June 2012 | 240 pages
Hardback | 978-0-19-989100-9 | ~~£22.50~~ **£16.87**



Nicolas-Louis De La Caille, Astronomer and Geodesist

Ian Stewart Glass

This is the first comprehensive biography of one of the greatest and most careful observational astronomers of all time. He mapped the southern sky and named many of the constellations. In addition, he contributed to geodesy, navigation, and celestial mechanics.

December 2012 | 200 pages
Hardback | 978-0-19-966840-3 | ~~£35.00~~ **£26.25**

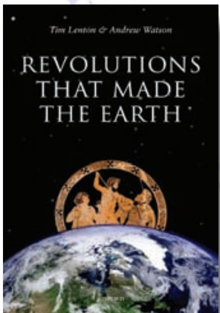
Higher Speculations

Grand Theories and Failed Revolutions in Physics and Cosmology

Helge Kragh

A historical account of highly ambitious attempts to understand all of nature in terms of fundamental physics. Presenting old and new 'theories of everything' in their historical contexts, the book discusses the nature and limits of scientific explanation in connection with concrete case studies.

January 2011 | 416 pages
Hardback | 978-0-19-959988-2 | ~~£35.00~~ **£26.25**

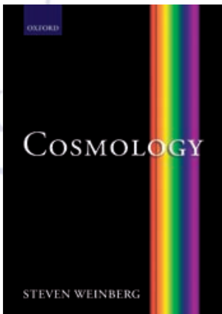


Revolutions that Made the Earth

Tim Lenton and **Andrew Watson**

The Earth that sustains us today was born out of a few remarkable revolutions, started by biological innovations and marked by global environmental consequences. Humanity's planet-reshaping activities may be the latest example. By understanding the past revolutions, we can help steer current global change toward a sustainable outcome.

January 2011 | 440 pages
Hardback | 978-0-19-958704-9 | ~~£29.95~~ **£22.46**



Cosmology

Steven Weinberg

This is a uniquely comprehensive and detailed treatment of the theoretical and observational foundations of modern cosmology, by a Nobel Laureate in Physics. It gives up-to-date and self contained accounts of the theories and observations that have made the past few decades a golden age of cosmology.

February 2008 | 616 pages
Hardback | 978-0-19-852682-7 | ~~£49.50~~ **£37.12**

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A&G
News and Reviews in Astronomy & Geophysics

Astronomy & Geophysics publishes news reviews and comment on topics of interest to astronomers and geophysicists. Topical material is preferred. Publication will be as fast as is compatible with referees' and authors' responses. Contact the Editor or see http://www.ras.org.uk for further information.

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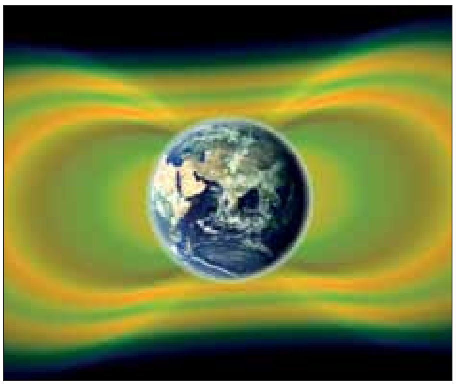

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Cover: An artist's impression of the Jupiter Icy Moons Explorer spacecraft (JUICE), with Jupiter and its icy moon Ganymede. This recently approved mission has strong UK involvement and will reach the Jupiter system in 2033. Find out why exploration of these distant bodies holds so many challenges and possibilities in the review on pages 2.14–2.20. (ESA)

EDITORIAL

Cosmic coincidence

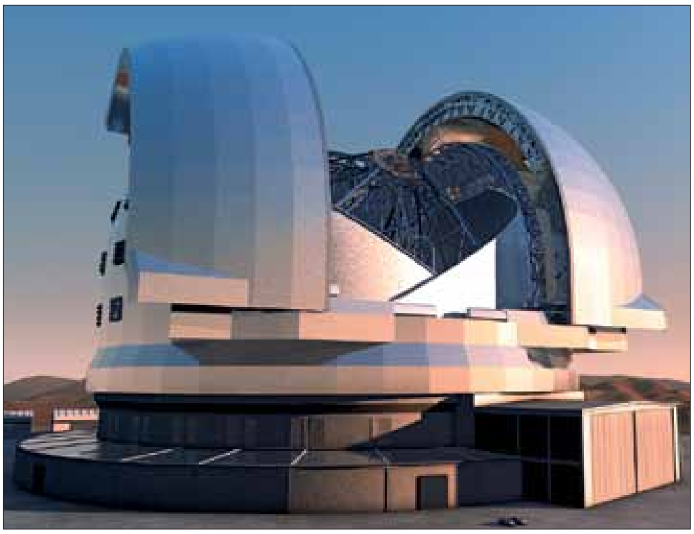
Sue Bowler, Editor

Scientists involved in outreach often wonder aloud what it would take to make their subject front-page news. The response to the unexpected meteor and fireball over Chelyabinsk in Russia in February suggests that surprise, a very loud noise and structural damage does the trick, although they are not likely to make it through the planning stage of a funding application. Joking aside, much of the public interest came from the realization – surprising to some – that impacts really can happen and we can't predict them all. That belief will be substantially reinforced by the very many film clips of the event available on the internet. It also helped that many people working in the field were involved in publicizing the expected close encounter with an asteroid that day, and so were ready to comment as the news came in. It is sobering to realize that neither of these bodies were big enough to be detected by existing routine searches for potentially hazardous bodies. Perhaps this cosmic coincidence will remind people outside astronomy that we don't really know what's out there in space – even the small stuff in our backyard. I'm pleased that the universe can still spring surprises –that's one of the reasons I enjoy science – but very aware that they could be a lot nastier than this one.

s.bowler@leeds.ac.uk

UK confirms funding for E-ELT

The UK government has announced investment of £88m in the European Extremely Large Telescope, putting UK scientists in leading roles in the development of instruments and technologies for the 39 m telescope and in a position to make the most of the scientific discoveries expected to come out of the new project.



The E-ELT will be the largest optical and infrared telescope ever built. (ESO)

"Not only will this new telescope considerably increase knowledge of the universe, its construction will drive growth and innovation for UK industry. This is why space is one of our eight great technologies," said David Willetts, Minister for Universities and Science, announcing the funding. "To top it off, the advances in technology that will result from this hugely challenging project will be a real asset to the UK and have knock-on effects for other sectors and areas of research."

STFC Chief Executive Officer Prof. John Womersley said: "E-ELT is one of the highest priorities for STFC and the UK astronomy community. It not only has the potential for enormous benefit to UK industry but will also be the world's pre-eminent astronomical observatory for many years to come."

The estimated cost of the E-ELT is €1.1bn (at 2012 prices), paid for by members of the European Southern Observatory. The £88m will be on top of the £18m annual UK subscription to ESO and will come from within the BIS science and research programmes budget. This total includes £35m which will be awarded by STFC within the UK to instrument production, via UK research institutions and industry.

The UK has already played a major part in the E-ELT project, leading the development of the science case, developing instrument designs, optical technologies and telescope systems, and developing manufacturing processes. The UK instrument programme will be delivered in close collaborations between Durham University, the University of Oxford, the University of Cambridge, the STFC's UK Astronomy Technology Centre in Edinburgh and RAL Space, together with leading international institutes.

UK industry has already won £9m worth of contracts, and that figure is predicted to increase as much as ten-fold before 2023 when construction is expected to be completed. The advanced manufacturing challenges presented by the project are providing UK companies with the opportunity to apply for contracts. A UK technology development centre based in North Wales is delivering prototypes for the primary mirror system, which could lead to the potential €100m order for UK industry to manufacture the production segments.

http://www.eelt.org.uk

The Chelyabinsk meteor. (Nikita Plekhanov)

A surprise from the skies

On 15 February, as observers were preparing to track asteroid 2012DA14 on its close approach to Earth, a smaller object burst into a bright fireball in the skies above Russia, sending out a shock wave that smashed windows. Hundreds of people were reported hurt, mostly by flying glass.

It is thought that a meteor about 20 m across with a mass of perhaps 11 000 tonnes disintegrated in the atmosphere in the region of Chelyabinsk, Russia, leaving a 6 m crater in lake ice. Initial estimates of the size of the body were smaller; the seismic and infrasound records of its passage and disintegration were used to estimate its mass after the event.

The coincidence of the two events raised public awareness of the impact threat. The private B612 Foundation, hoping to launch a space telescope to locate potentially hazardous bodies, estimated that their Sentinel satellite would find 50% of bodies this size in space. And Deep Space Industries pointed out that their technology – small spacecraft to detect and eventually mine asteroids passing close to Earth – would be able to assess hazardous bodies *in situ*.

Academics in California have proposed deflecting or destroying incoming bodies using solar powered lasers. "All the components of this system pretty much exist today," said Prof. Gary B Hughes, from California Polytechnic State University, San Luis Obispo. "Scaling up would be the challenge." It is claimed that a system 10 km across (100 times the size of the International Space Station) could obliterate an asteroid 500 m across in a year.

http://bit.ly/ZdfiS0
http://deepspaceindustries.com/learn-more
http://bit.ly/YZ7a5r

WISE eyes on the Orion Nebula

The Orion Nebula (Messier 42) in infrared from NASA's Wide-field Infrared Survey Explorer satellite. Hot stars appear blue, while cooler objects such as dust, appear green and red. The clump of young stars at the centre of the cloud are heating the hottest, white, dust. This view is 100 light-years across, spanning about six times the width of the full Moon on the sky. (NASA/JPL-Caltech/WISE Team)
http://1.usa.gov/12z9sP0

Target Jupiter: National Astronomy Week 2014

In 2014 the National Astronomy Week (NAW) will focus on Jupiter and the organizing committee is seeking direction on what supporting materials would be most useful to those planning public activities.

Next year, Jupiter will be at its highest in UK skies for many years and to celebrate the event UK astronomers will be holding another National Astronomy Week, on 1–8 March (lasting eight days in order to include two weekends). "We expect to see the best photos ever of the planet taken from the UK in 2014," says NAW chair Dr Robert Massey. "And it will be a great opportunity for everyone to get a splendid view of the giant planet."

Both amateur and professional astronomers across the UK will be opening up their telescopes to the public for the event. While some are in large observatories, many will be in back gardens or even on village greens. "This is the chance for Britain's amateur astronomers to invite their neighbours to see what it's all about," says Massey.

In order to help everyone interested make the most of the opportunity, the NAW committee intend to prepare (free) PowerPoint presentations of pictures and outline talks for departments and societies who lack an in-house Jupiter expert. They could also be adapted for talks in schools, or to the general public who come along to an event where suitable facilities exist. So the committee would welcome comments about whether people would actually use these presentations if they were available. What the committee would like to know is:

- Would you be likely to use such a presentation aimed at the general public?
- How long would you like it to be – 20, 40 or 60 minutes (or other)?
- Would you also like a presentation tailored for children (10–14)?

People can email via the website with their comments about this or the week in general, which would help with the planning.

"We hope for some breathtaking results," says NAW coordinator Dr Sandra Voss. "Many observers should get their best view ever. And we could see the best images ever taken, because the UK has some of the best astronomical photographers in the world. Cameras and image-processing software are much improved compared with 2002, the last time when Jupiter was as high."

The NAW website has plenty of information on Jupiter and what can be seen on the planet, as well as details of other objects visible during NAW 2014. Full details of "open telescope" evenings will be posted on the site nearer the time.
http://www.astronomyweek.org.uk

NEWS IN BRIEF

Prize for SKA author

The inaugural Institute of Physics Journalism Prize, designed to inspire the next generation of physicists, has been won by Anil Ananthaswamy for his article "Hip hip array", which focuses on the Square Kilometre Array, an international project to design and build the largest radio telescope ever conceived. The prize is sponsored by the IoP and the Science and Technology Facilities Council. Terry O'Connor, head of communications at STFC, said: "With the SKA project office located in the UK at Jodrell Bank, and UK researchers and government heavily involved at every stage, we're delighted that the winning article highlighted this fascinating and ambitious project."
http://www.iop.org

UN lists space weather

The United Nations has added space weather – the changing influence of the Sun on Earth and nearby space – to the list of key challenges to the planet considered by their Committee on the Peaceful Uses of Outer Space. COPUOS is a forum for the development of international cooperation on problems that affect all countries of the world. The topic will be discussed alongside the risks from orbital debris and impacts from near-Earth objects when COPUOS meets. This year the committee heard about the widespread effects of solar activity reaching Earth, on satellite communications, air transport, technologies using global positioning systems, such as directional drilling, and the effects of induced currents on power transmission and corrosion control in fuel pipelines.
http://bit.ly/12uMngj

Mars came to Morocco

The Austrian Space Forum (OeWF) staged a series of experiments involving 23 nations in a Mars analogue site in the Northern Sahara in February this year, with an emphasis on field tests for the OeWF's two analogue Mars spacesuits, Aouda.X and Aouda.S. The simulations also involved a realistic time delay of ten minutes each way, to reflect the actual difficultiesin communication between Mars and Earth.
http://bit.ly/WKrcPv

NEWS IN BRIEF

Win a trip to La Palma

An RAS Fellow, Peter Sinclair, is organizing a fundraising drive for charity and is offering a prize that may be of interest to Fellows: a guided tour of the Instituto de Astrofisica de Canarias in La Laguna Tenerife and the Roque de los Muchachos Observatory, including visits to the 4.2 m William Herschel Telescope and 10.4 m Gran Telescopio Canarias. The prize will be auctioned on 8 May in support of the Flavasum Trust and the Robert Levy Foundation, which work against knife crime among young people.

http://www.theflavasumtrust.org/auction

Bullerwell Lecture 2013

The British Geophysical Association's Bullerwell Lecture will be held at the European Geosciences Union annual assembly in Vienna on Tuesday 9 April. The 2012 Bullerwell Lecturer Derek Keir (University of Southampton) will discuss "Magmatism and deformation during continental breakup". Derek will repeat his lecture at the BGA Postgraduate Research in Progress meeting to be held in Cambridge in September. Nominations for the 2013 Bullerwell Lectureship are now open, with a deadline of 31 August 2013. The lectureship, named after William Bullerwell, first chief geophysicist of the (predecessor to the) British Geological Survey, is a prestigious appointment for an outstanding early-career geophysicist. The nomination form is on the BGA website.

http://www.geophysics.org.uk

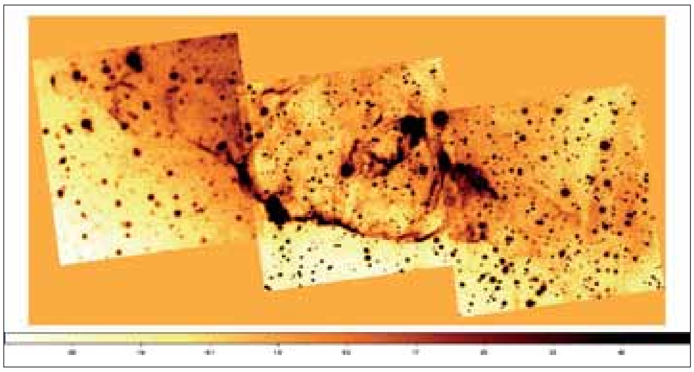
Digital pathology

Analytical algorithms developed for astronomy have proved valuable for the evaluation of tissue biomarkers in oncology. Astronomers, faced with large volumes of data, have developed robust and sophisticated automated analysis, methods that transfer effectively to mapping protein expression in breast cancer samples, and has the potential to make new avenues of research feasible. Results of the collaboration between astronomers and cancer researchers at the University of Cambridge has been published in *Nature* by Ali *et al.*

http://www.nature.com

Planetary nebula evolution from Peloponnese

The first research to come from a new Greek telescope continues the national tradition of astronomy that stretches back more than 2500 years. Panos Boumis of the National Observatory of Athens and John Meaburn of the University of Manchester have used the new 2.3 m Aristarchos telescope, at Helmos Observatory in the Peloponnese Mountains, Greece, to examine an enigmatic stellar system that appears to be a binary star inside a planetary nebula.



(Left): The enclosure of the new 2.3 m Aristarchos telescope, sited at Helmos Observatory in Greece. (P Boumis, National Observatory of Athens)
(Above): An image of the giant lobes of the planetary nebula KjPn 8 in the light of the emission lines of hydrogen and singly ionized nitrogen, obtained with the narrowband camera on Aristarchos. Detailed measurements of the lobes have allowed the determination of their expansion velocity, distance and ages. The results indicate their origin in a remarkable eruptive binary system. (P Boumis/J Meaburn)

Planetary nebula KjPn8 was discovered on Palomar Observatory Sky Survey plates in the 1950s. In the 1990s, Mexican astronomers discovered giant lobes around the system, one quarter of a degree across, but it was not until 2000 that the Hubble Space Telescope revealed the central star. Boumis and Meaburn set out to study the expansion of this system, installing a narrowband imaging camera on the Aristarchos telescope, the largest aperture instrument in southeastern Europe.

The velocity and increasing size of the expanding material indicated that the lobes around KjPn8 were thrown out in three phases 3200, 7200 and 50 000 years ago. The inner lobe of material is expanding at 334 km per second, suggesting it originates in an intermediate luminosity optical transient (ILOT) event. ILOTs are caused by the transfer of material from a massive star to its less massive companion, in turn creating jets that flow in different directions.

Boumis and Meaburn believe that the core of KjPn8 is therefore a binary system, where every so often ILOT events lead to the ejection of material at high speed. They have published their results in *Monthly Notices of the Royal Astronomical Society*.

Boumis is delighted to see the first results from the new telescope giving clues to the history of such an intriguing system: "Greece is one of the global birthplaces of astronomy, so it is fitting that research into the wider universe continues in the 21st century. With the new telescope we expect to contribute to that global effort for many years to come."

http://bit.ly/16amYrd

Who names exoplanets?

A space start-up company is offering the opportunity to submit names for exoplanets – for a small fee – with the intention of using much of the proceeds to fund grants for space exploration, research and education. Meanwhile, the International Astronomical Union, through Commission 53 Extrasolar, remains against the idea of popular names for exoplanets, and is consulting its members during 2013.

By convention, the IAU agrees on nomenclature for solar system planets, planetary features, dwarf and minor planets and comets. The IAU represents professional astronomers and their work has focused on clear identification for scientific purposes. Uwingu, a commercial concern set up by a group of leading names in astronomy and planetary sciences, wants to involve the public in naming exoplanets in order to boost the connection that people feel with space.

"This is a first step in democratizing planet naming," said Uwingu CEO Dr Alan Stern. "It's a new way for the people of Earth, of every age, of every nation, of every walk of life to personally connect to space discoveries."

It costs $4.99 to suggest a name (although discounts are available for bulk buys). Nominations then go into a database from which "astronomers and others can select" names for exoplanets, according to Uwingu.

The public interest in undeniable, with fictitious planets such as Tatooine from *Star Wars* cited to describe planetary discoveries. But the idea of naming exoplanets may falter under the sheer numbers likely to be found, as the IAU website suggests: "If planets are found to occur very frequently in the universe, a system of individual names for planets might be found equally impracticable as it is for stars."

http:///www.iau.org
http://www.uwingu.com

Geophysical picture prize

Do you have a spectacular geophysical image? If so, the British Geophysical Association would like to see it!

If you enter the BGA Image Competition you could win £200 and a year's membership of one of the BGA parent societies, the Royal Astronomical Society or the Geological Society of London. The BGA is looking for dramatic fieldwork photos, spectacular images of numerical simulations, stimulating laboratory photos, or any clearly geophysical images.

Full details are given on the BGA website. The competition closes at midnight on 31 August 2013, images must be in JPEG format and entrants must agree to the BGA using their image for promotion, free of charge. Please submit images by email (only) to glxjc@bristol.ac.uk, with "BGA image competition" as the subject.

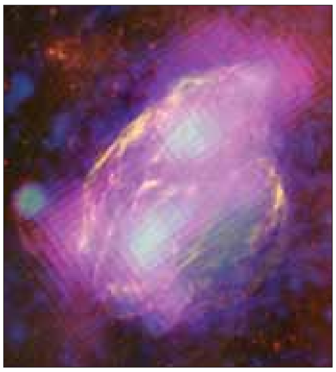
http://www.geophysics.org.uk

Cosmic rays from supernova remnants

How and where do cosmic rays reach such high energies? NASA's Fermi satellite has identified supernova remnants as their source, through an acceleration mechanism involving repeated passages through shocks.

Cosmic rays are mainly protons, with some electrons and atomic nuclei, moving at close to light speed. Their origins have been obscure because cosmic rays do not travel in straight lines in space. But the gamma rays produced when they interact with matter do travel directly from their sources, which can thus be identified.

The Fermi results concern two supernova remnants, IC443 and W44, that are expanding into cold, dense interstellar gas clouds. These clouds emit gamma rays when struck by high-speed particles. Scientists had not known which atomic particles are responsible for emissions from the gas clouds because cosmic-ray protons and electrons give rise to gamma rays with similar energies.



The W44 supernova remnant in the molecular cloud that formed its parent star. Fermi's LAT detects GeV gamma rays (pink) produced when gas is bombarded by cosmic rays, primarily protons. Radio observations (yellow) from the Karl G Jansky Very Large Array, and infrared (red) data from the Spitzer Space Telescope reveal filamentary structures in the remnant's shell. Blue shows X-ray emission mapped by ROSAT. (NASA/DOE/Fermi LAT Collab., NRAO/AUI, JPL-Caltech, ROSAT)

Analysis of four years of data has revealed that the gamma-ray emission from both remnants involves a neutral pion, produced when cosmic-ray protons smash into normal protons. It quickly decays into a pair of gamma rays with a characteristic energy spectrum – the fingerprint of cosmic rays. The acceleration mechanism involves a charged particle repeatedly crossing the explosion's leading shock wave. Each round trip through the shock boosts the particle's speed by about 1%.

http://1.usa.gov/Z0LI03

Exoplanet study says intelligent civilizations scarce

As the numbers of exoplanets, confirmed and candidate, rise, the question of how many of them might host life becomes more pressing – and leads to speculation about the number of civilizations that might exist. A systematic search among stars with planets for radio signals that could signify intelligent civilizations suggests that very few exist.

Scientists at the University of California, Berkeley, used the Green Bank Telescope in West Virginia to look for intelligent radio signals from planets around 86 of the stars identified by the Kepler mission as having confirmed or candidate planets. While discovering no telltale signs of life, the statistics of the sample indicate that fewer than one in a million stars in the Milky Way galaxy have planetary civilizations advanced enough to transmit beacons that we could detect.

The 86 stars were chosen from among the Kepler mission's candidates that show evidence of multiple planets and the potential for some of those planets to have liquid water on their surfaces. The team used the Green Bank Telescope to collect five minutes of radio emissions from each of the stars, in the frequency range 1.1–1.9 GHz that on Earth falls between the mobile phone and television bands. They then searched the data for high-intensity signals with a narrow bandwidth (5 Hz) that are only produced artificially – presumably by intelligent life. Most of the stars were more than 1000 light-years away, so only signals intentionally aimed in our direction would have been detected. In future, more sensitive radio telescopes such as the Square Kilometre Array should be able to detect much weaker radiation, perhaps even unintentional leakage radiation from civilizations like our own.

The team plans more observations with the Green Bank Telescope, focusing on multi-planet systems in which two of the planets occasionally align relative to Earth, allowing them to take advantage of putative communications between the planets. Andrew Siemion and Dan Werthimer and colleagues' findings are published in *The Astrophysical Journal*.

http://arxiv.org/abs/1302.0845

Planets around white dwarfs could harbour life

White dwarf stars could have planets and those planets could be like Earth, with oxygen and water in their atmospheres and possibly even life – and they could be easy identified in only a few hours observation time with the James Webb Space Telescope, according to astrophysicists modeling exoplanet detection.

Avi Loeb, Director of the Institute for Theory and Computation at the Harvard-Smithsonian Institute for Astrophysics (CfA), argues that the small size of white dwarfs – typically the size of Earth – and the close orbits of planets in their habitable zones mean that Earth-sized planets would be easy to find through the transit method. This also allows analysis of the atmospheres of the planets, through spectroscopy of the light from their stars passing through the atmospheres at the start and finish of the transit. Loeb and Dan Maoz of Tel Aviv University used a synthetic spectrum of a habitable planet in an orbit in the habitable zone of a white dwarf to examine what the James Webb Space Telescope would see and found that just a few hours observing time would be enough to detect oxygen and water and indicate a habitable or even life-bearing planet.

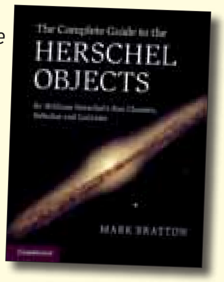
The planet may not be very homely, however. Any original planets formed around a star are likely to be destroyed when the star swelled to become a red giant, before shrinking to a white dwarf, so white dwarf planets would be captured later, or outer planets that migrated inwards – or possibly planets that formed late in the life of the star. And while white dwarfs slowly cool and fade over time, they can retain heat long enough to warm a nearby world for billions of years. But a habitable planet would circle the white dwarf once every 10 hours at a distance of about a million miles. Loeb and Maoz publish this research in *Monthly Notices of the RAS*.

http://hvrd.me/YBAOhU

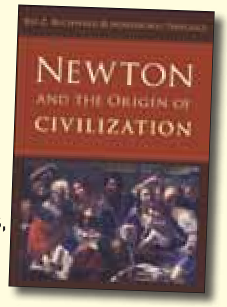
Library News

RAS Librarian Jenny Higham brings news of new books and how to find them in the Society's Library at Burlington House.

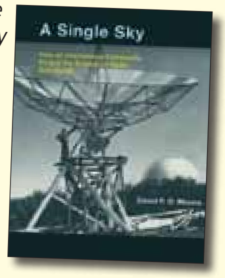
Recent acquisitions to the RAS Library, given with their library classifications, include:



- Bratton M 2011 *The Complete Guide to the Herschel Objects: Sir William Herschel's Star Clusters, Nebulae, and Galaxies* (Cambridge University Press, Cambridge) QB 64 BRA
- Buchwald J Z and Feingold M 2013 *Newton and the Origin of Civilization* (Princeton University Press, Princeton) QB 36 Newton



- Clancey W J 2012 *Working on Mars: Voyages of Scientific Discovery with the Mars Exploration Rovers* (MIT Press, Cambridge, Mass.) QB 642 CLA
- Dekker E 2012 *Illustrating the Phaenomena: Celestial Cartography in Antiquity and the Middle Ages* (Oxford University Press, Oxford) QB 65 DEK
- Munns D P D 2013 *A Single Sky: How an International Community Forged the Science of Radio Astronomy* (MIT Press, Cambridge, Mass.) QB 475 MUN



You can find more recently catalogued titles, both newly published and historic, by visiting the Library's online catalogue and clicking on the "What's new" section. Do also check out the new books shelf in the Library.

The Library has a limited budget for new acquisitions and so presentation copies from Fellows (in particular of their own publications) are gratefully received. Such gifts will be recorded for posterity and will be given a bookplate displaying the donor's name. Please contact the Librarian Jenny Higham if you have a title you wish to present.

jhigham@ras.org.uk
http://bit.ly/XTprTo

Space Shorts

Dragon returns to ISS

The second flight to the International Space Station by the company SpaceX succeeded with only a minor hitch in the condition of the Dragon spacecraft, which was detected and remedied after its separation from the Falcon 9 rocket. Dragon carried supplies for the ISS, including materials for science investigations. After three weeks, Dragon will return a payload including research results, education experiments and space station hardware. The launch on 1 March 2013 was the fifth consecutive successful launch for the Falcon 9 rocket.
http://spacex.com

Next Mars mission

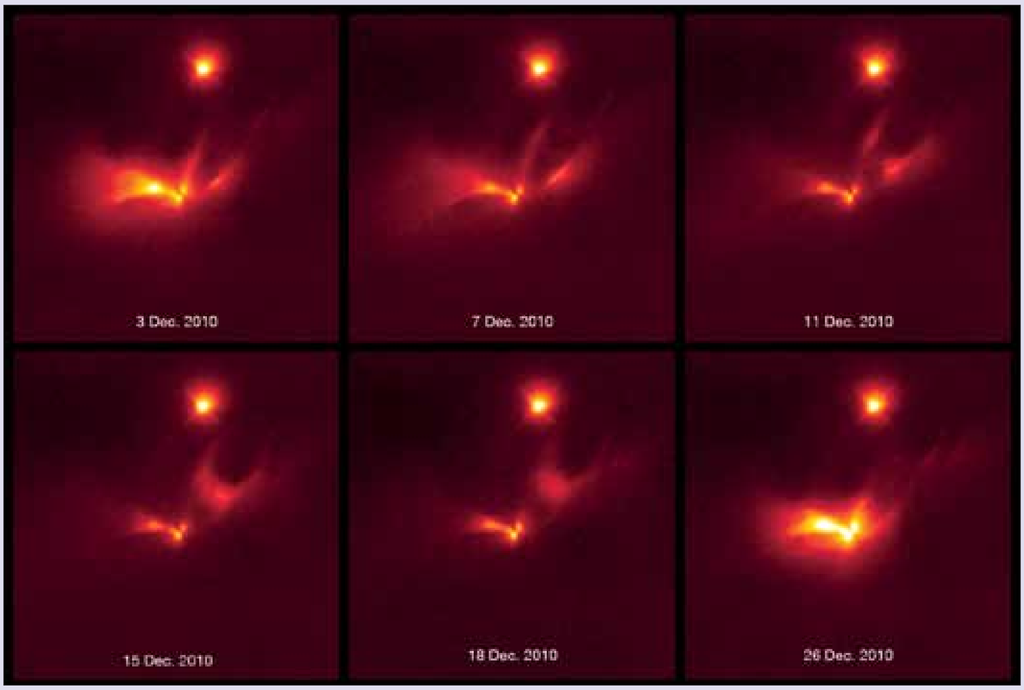
NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft is undergoing tests before final preparations for launch in November 2013. MAVEN will address mechanisms for the loss of the martian atmosphere over time, with a view to understanding what atmospheric evolution means for the martian climate. Testing includes vibrational and other simulations to ensure the spacecraft and instruments can survive launch, as well as environmental testing that simulates extremes of temperature and pressure in space.
http://1.usa.gov/XKOele

Smallest space 'scope

The smallest space telescope in the world, the BRIte Target Explorer (BRITE), a pair of nanosatellites each just 20 cm across with a mass of less than 7 kg, are now in orbit. The Space Flight Laboratory of the University of Toronto Institute for Aerospace Studies favours such nanosatellites because they are relatively cheap and quick to design, test and deploy. BRITE is the first nanosatellite mission intended for astronomy, and the first-ever astronomy constellation – more than one satellite working towards a common objective. BRITE will take photometric measurements, collecting data useful for identifying brightness variations arising from starspots, transiting planets and oscillations within the star itself. The BRITE constellation will eventually comprise six satellites.
http://universe.utoronto.ca/BRITE

Mission update

Hubble discovers flashing protostar



Short-lived but regular bursts of light from a dusty protostar are thought to represent material pulled into a pair of protostars from the debris disc around them. This sequence of images from the Wide Field Camera 3 on the NASA/ESA Hubble Space Telescope shows a pulse of light from the protostellar object LRLL 54361. Most if not all of this light results from scattering off circumstellar dust in the protostellar envelope. There appears to be a disc, edge-on, at the centre, with three separate structures interpreted as outflow cavities. The periodicity of the flashes – 25.3 days – led James Muzerolle of the Space Telescope Science Institute in Baltimore to suggest that a binary pair may be responsible. When material in a circumstellar disc is dumped onto a pair of forming stars, it unleashes a blast of radiation each time the stars orbit close to each other. The Hubble observations show an optical illusion known as a light echo. It looks like gas is erupting from the protostar, but these pulses are actually flashes of light propagating through the surrounding dust and gas and reflecting towards the observer: there is no substantial physical motion within the cloud over these timescales. (NASA, ESA and J Muzerolle [STScI])
http://bit.ly/13EoMt7

ESA picks JUICE instruments

ESA's Science Programme Committee has approved the selection of the suite of 11 instruments for the Cosmic Visions mission to Jupiter and its moons Ganymede, Callisto and Europa. JUICE – the JUpiter ICy moons Explorer – has a planned launch date of 2022 and should arrive at Jupiter in 2033.

The instruments include cameras and spectrometers, a laser altimeter and an ice-penetrating radar. The mission will also carry a magnetometer, led by researchers at Imperial College London, plasma and particle monitors, and radio science hardware. JUICE will not, however, carry thermal infrared detectors, limiting what can be learnt about jovian meteorology from the mission.

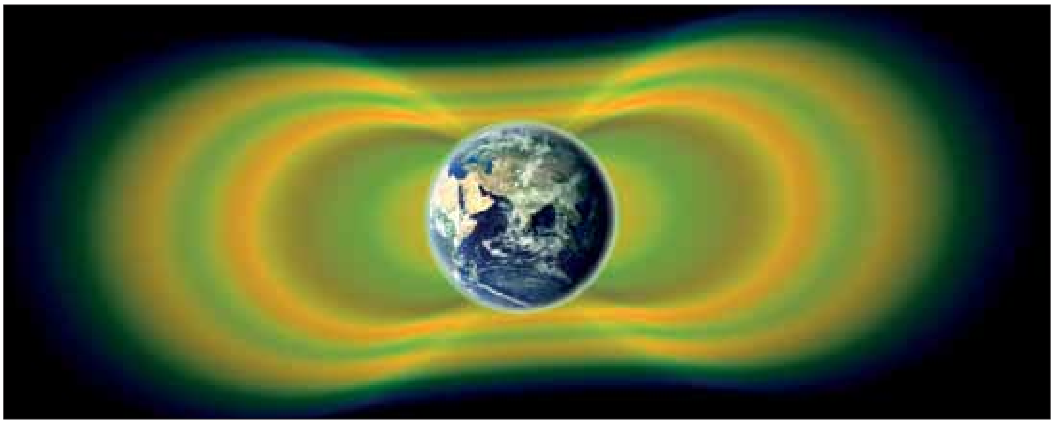
The instruments will be developed by scientific teams from 16 European countries, the US and Japan, through corresponding national funding. Science targets include Jupiter's atmosphere and magnetosphere, the structure and interactions of the three icy moons, plus Io, with their host planet, and the spacecraft will finish in orbit around Ganymede. One of the aims is to understand the thicknesses of the icy crusts on Europa and Ganymede that appear to overlie liquid oceans.

Dr Chris Castelli, acting director of science, technology and exploration at the UK Space Agency, said: "JUICE is an excellent example of the type of big national missions that UK scientists continue to win key involvement in. With their help, JUICE will make the most detailed characterization of the jovian system ever obtained, revealing fresh insights into the habitability of the 'waterworlds' orbiting the giant planets in our solar system and beyond."
http://bit.ly/109Xmdw

Probes find new radiation belt

NASA's pair of space-weather satellites, the Van Allen Probes, have discovered that Earth can have a third radiation belt, a new configuration of higher energy particles further out in space than the known pair of radiation belts (figure 1).

The discovery came shortly after launch of the spacecraft at the end of August last year. In a change to mission plans, the Relativistic Electron Proton Telescope (REPT)



1: Sketch of Earth's radiation belts in yellow, with "slots" between them in green, in the three-belt configuration seen in September 2012 by the Van Allen Probes. (NASA/Van Allen Probes/Goddard Space Flight Center)

was switched on just three days after launch, so that its data collection would overlap with the final observations of another mission, SAMPEX, before its satellite re-entered Earth's atmosphere. REPT was able to observe as energy from the Sun changed the configuration of the radiation belts and led to the formation of a third, at an altitude of about 3–3.5 Earth radii.

The two known radiation belts, the Van Allen Belts, are zones of magnetically confined energetic charged particles that have a stable structure of two belts at different altitudes encircling the Earth. Bursts of energy from the Sun are known to change the configuration of the belts, and boost the energy of the particles they hold, but these data are the first to show the formation of a third belt, further out than the existing two, that persisted until another solar event on 1 October restored the more usual configuration.

Researchers working on the Van Allen Probes data describe thenew configuration as involving a "storage ring", with highly relativistic electrons with energies of more than 5 MeV moving outwards at the same tiem as changes in the second radiation belt. The data have been published in Science by Baker *et al.*

The Van Allen Probes study the effects of solar radiation on the Earth through the changes to the radiation belts, which so far has been found to be very variable. The appearance of the third radiation belt, its persistence and subsequent disappearance remain intriguing, but it is only because these spacecraft are in a position to collect such detailed data that the structure and processes involved are becoming clear.

Understanding changes to the radiation belts and the highly energetic particles they hold are important for satellites and all their associated technology on the ground. The high levels of radiation in the belts can damage satellite hardware; mapping them and how their positions and configuration change is a priority in the field of space weather.

http://www.nasa.gov/vanallenprobes

Kepler spots tiny planets

The Kepler mission has found an exoplanetary system in which the smallest planet is smaller than Mercury. Kepler-37b is only just bigger than the Moon and orbits with a planet about the size of Venus and one twice the size of Earth. While Kepler's detections of such systems are limited to the brightest stars it can observe and those that shine steadily, the fact that planets exist around those stars means that they are likely to be common around more distant stars as well.

Kepler-37's host star belongs to the same class as the Sun, although it is slightly cooler and smaller. All three planets orbit the star within Mercury's orbital distance: Kepler-37b orbits every 13 days at less than one-third Mercury's distance from the Sun, for example, with an estimated surface temperature of 700 K. Kepler-37c and Kepler-37d orbit every 21 days and 40 days, respectively.

Kepler finds planets by measuring the periodic decreases in a star's brightness as the planets cross its face; estimating the planet's diameter depends on knowing the star's size. For Kepler-37, the star's size was found to 3% accuracy through asteroseismology, using the Kepler satellite's data on periodic brightness variations of the star to determine its modes of vibration. This star is the smallest for which such asteroseismological analysis has been carried out, thanks to Kepler data.

http://1.usa.gov/101zMvR

Particle speeds shock Cassini

Particle acceleration at the bow shock of planets is a common process in the solar system, but data from the NASA/ESA/ASI's Cassini spacecraft suggest that, in some circumstances, such shocks can accelerate particles to relativistic energies, similar to those thought to generate cosmic rays in supernova remnants.

Cassini has crossed Saturn's bow shock many times as it has explored the planet, moons and rings, but on one crossing in 2007, the spacecraft detected an Alfvén Mach number of about 100, compared to the normal value of about 12 associated with this shock. The research team ascribe this acceleration to the fact that the shock vector and Saturn's magnetic field lines were almost parallel; on most occasions that Cassini had crossed the bow shock, the shock vector had been close to perpendicular to the field.

The findings confirm that, at high Mach numbers like those of the shocks surrounding supernova remnants, quasi-parallel shocks can become considerably more effective electron accelerators than previously thought. This result sheds new light on the complex process of cosmic particle acceleration. The results were published by Masters *et al.* in *Nature Physics.*

http://bit.ly/101Ahpv

NASA joins ESA Euclid mission

The ESA Euclid mission to study dark matter and dark energy has taken another step forward with an agreement for NASA to provide 20 detectors for the near-infrared camera, which will operate alongside a visible-wavelength camera. The instruments, telescope and spacecraft will be built and operated in Europe.

Euclid will use a 1.2 m diameter telescope and the two instruments to map the 3D distribution of up to 2 billion galaxies and dark matter associated with them, spread over more than one-third of the sky and 10 billion light-years (up to a redshift of approximately 2). There will be a wide survey covering 15 000 square degrees, and a deep survey across 40 square degrees. Euclid is optimized to answer one of the most important questions in modern cosmology: why is the universe expanding at an accelerating rate, rather than slowing down due to the gravitational attraction of all the matter in it?

The Euclid consortium of close to 1000 scientists from 13 European countries and the US will also be joined by 40 US scientists nominated by NASA.

http://bit.ly/W2ui4d

Curiosity drills first sample

Curiosity, NASA's Mars Science Laboratory rover at work on Mar, has drilled its first rock sample and delivered the resulting powdered rock samples to the Chemistry and Mineralogy instrument and the Sample Analysis at Mars instruments.

The Curiosity team examined four potential drill sites using the Alpha Particle X-ray Spectrometer and the ChemCam laser, after brushing away surface dust with the Dust Removal Tool and taking a close look with the Mars Hand Lens Imager. The rock chosen for the first drilling is known as "John Klein", within the shallow Yellowknife depression in Gale Crater.

The drill on Curiosity excises a 1.6 cm diameter hole, pulverizing the rock rather than preserving a drill core, and collecting the fine debris for analysis.

Curiosity's goal is to find signs of past climate and life on Mars; minerals and stable isotope ratios preserved within the rocks will be key lines of evidence.

http://1.usa.gov/Z72ixa

Debris discs, Vesta and the solar cycle

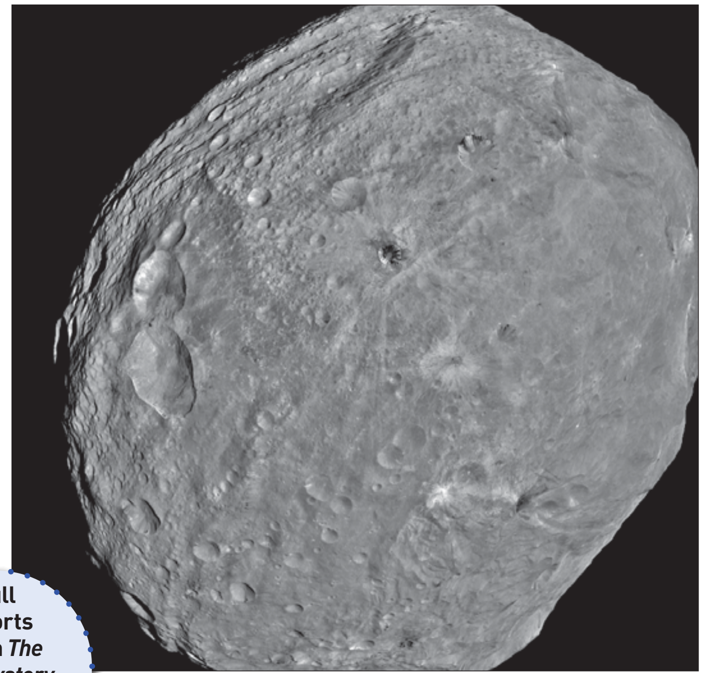
MEETING REPORT For the RAS Ordinary A & G meeting in January, James Dungey was present to hear the inaugural James Dungey Lecture by Prof. Peter Cargill. In February the Harold Jeffreys Lecture was given by Prof. Bill Chapman. Both will be reported in future issues. Here Sue Bowler summarizes the other talks.

Vesta in the light of Dawn

Prof. Chris Russell, University of California at Los Angeles, USA.

Dawn is NASA's ninth Discovery craft and arrived at Vesta, the second most massive body in the Asteroid Belt, in July 2011 and left in September 2012. Prof. Russell described Vesta itself as an intact survivor of the collisional processes in the early solar system, a basaltic protoplanet marked by impact structures. Dawn's spectroscopic data confirm that Vesta is the source of the HED (Howardite–Eucrite–Diogenite) meteorites, on the basis of Fe/Si and Fe/O ratios. There is also good evidence that this protoplanet has an iron core, as well as evidence of water at the surface, which is surprisingly varied in colour. A correlation of hydrogen-rich regions with low surface brightness suggests organic compounds darkening the surface. All in all, Vesta is big enough to show planetary processes from the early history of the solar system, without the reworking of atmosphere, oceans and volcanoes that have largely erased evidence of processes operating at this time from the geological record on Earth.

http://1.usa.gov/YFUro0



The primitive battered surface of giant asteroid and protoplanet Vesta imaged by NASA's Dawn spacecraft on 24 July 2011, at a distance of about 5200 km. (NASA/JPL-Caltech/UCLA/MPS/DLR/IDA)

Full reports are in *The Observatory*
http://bit.ly/UMdDy9

The solar cycle in the heliosphere

Dr Matt Owens, RAS Fowler Prize Winner, University of Reading.

Dr Owens described collaborative work to model the heliospheric magnetic flux from the solar cycle at the photosphere, using sunspot numbers and data from distant spacecraft such as Ulysses and other spacecraft in Earth orbit. Dr Owens pointed out that the sunspot number is a threshold; flux can be emerging from the photosphere without the formation of spots, as appears to have happened in the Maunder minimum. The total heliospheric magnetic field has varied in phase with sunspot number for the past three cycles, and it appears that these solar cycles during the Space Age are bigger than usual, forming a grand solar maximum (GSM). We seem to be close to solar maximum at the moment – the lowest solar maximum since the start of the 20th century. Dr Owens then considered what happens at the end of a GSM, and concluded that we are living in interesting times. In the ice core record of the past 9000 years, there have been 24 similar GSMs. Twice there was another GSM in the following 50 years, and twice there was a Maunder minimum event in the following 50 years.

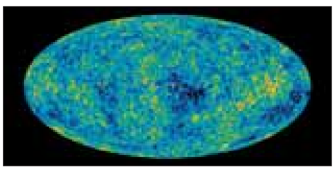
http://bit.ly/Y3Fvy3

Hunting for relics from the early universe in the CMB

Dr Hiranya Peiris, RAS Fowler Prize Winner University College London.

Dr Peiris described the idea of the cosmic bubble as a test of our understanding of the expansion and overarching structure of the universe, testing ideas with the WMAP seven-year Cosmic Background Radiation (CMB) data. Essentially, we may inhabit our local universe, as if in one of many bubbles held within a different phase, like bubbles of steam in water. Expansion could slow or stop in a bubble, while continuing in the surrounding phase. For example, perhaps inflation stopped only locally, but continued elsewhere in the universe; we could inhabit an eternally inflating universe. And in that case, if our bubble were not alone, collisions between bubbles would leave marks in the CMB, in the form of long wavelength fluctuations, localized in real space and with azimuthal symmetry and a causal boundary. Dr Peiris described searching for such effects in the CMB data using blind analysis techniques taken from particle physics and Bayesian model selection analysis. Results were inconclusive from the seven-year data, but the idea may be testable with the 10-year data.

http://bit.ly/Xr1qlz



This all-sky image of the CMB reveals temperature fluctuations from 13.7 bn years ago. (NASA/WMAP Science Team)

Fitting the Kuiper Belt in to the debris disc zoo

Dr Jane Greaves, University of St Andrews, UK.

Dr Greaves began by introducing the concept of extrasolar comets, pointing out that the Kuiper Belt is more visible than the Sun at submillimetre wavelengths. Belts of millimetre-sized debris around other stars absorb starlight and emit at lower wavelengths, making these belts of orbiting grit one of the most visible aspects of other planetary systems. She described the results of the SCUBA2 survey SOMS, which is tripling the number of systems known with debris discs in the submillimetre. The Herschel Space Observatory has also determined the composition of some of the debris, finding olivine (an iron magnesium silicate) around β Pictoris and watery ice in other protoplanetary discs – together the recipe for planets. The existence of comet belts may also be a factor in planetary system evolution, possibly driving many more planetary impacts in systems with significantly more comets.

http://star-www.st-and.ac.uk/~jsg5

PROFILE: Harvey Butcher

Ragbir Bhathal interviews Harvey Butcher, a well-travelled astronomer known for his discovery of the Butcher–Oemler effect and for the design and implementation of advanced astronomical instrumentation including LOFAR (LOw Frequency ARray radio telescope), as well as his contributions to multidisciplinary science innovation and public outreach.

As a young boy it was *Scientific American* magazine that fired Harvey Butcher's enthusiasm to become an astronomer. A particular article caught his imagination, on high-resolution spectra of cool stars: "This was in my high school years and I didn't realize that if you take a spectrum of the Sun or the stars, you see many spectral lines, and they tell you about the physics and the composition of the distant stars. I just thought that was amazing. I wanted to do that!" He was very keen to become a professional astronomer but his father, a physician, was less impressed. "He did not encourage me to be an astronomer by any means," Butcher recalled. "He was supportive, as a father should be, but very sceptical." Nevertheless, the young Butcher went to the California Institute of Technology to study astronomy.

He found the place daunting. "The competition at Caltech was something that I still look back on with ambivalence. Arriving freshmen were taken off to an orientation camp in the mountains, and I remember vividly one of the first things that the president of the university did was, he asked us each to look to his left and then to his right. And then he said, 'One of you three will flunk out, fail at university, and have to leave.' That was a bit of a shock because I wasn't prepared for that kind of competition."

While stressful, it was also intellectually exciting and challenging. Butcher arranged a part-time job at the Mount Wilson Observatory, where he met many famous astronomers as they came to observe. His role was to help with the development of infrared photometry in one of the first surveys of the sky at infrared wavelengths (the Neugebauer–Leighton Two Micron Sky Survey). He also spent a lot of time talking to Allan Sandage, who was "very, very encouraging, very helpful and very critical".

Butcher graduated from Caltech in 1969, during the Vietnam War. He was not called up for war service but had already become critical of US society. "It didn't feel to me the kind of society I really wanted to live in. So I began to look around." Sandage suggested that Mount Stromlo would be an interesting place and Butcher agreed, for two scientific reasons. "One was the southern sky. I'd never seen the southern sky and the Magellanic Clouds. The second was that I knew that the Coude spectrograph at the Stromlo 74 inch telescope was built by Theodore Dunham." Dunham had built the spectrograph for the 100 inch at Mount Wilson, so Butcher reckoned that the later version at Mount Stromlo would be even better. There was another, non-scientific reason for going to Australia: "I discovered that there were no lecture courses at Mount Stromlo! I was completely fed up with sitting in lecture courses and taking exams. The idea of having four years to do nothing but a research project was unbelievably attractive. When I arrived I found students were treated almost as staff members for access to telescopes and other facilities. In hindsight it was one of the best decisions I ever made."

Nucleosynthesis

Butcher began his PhD under the supervision of Mike Bessell, a young astronomer who was making a name for himself in the study of variable stars, and Alex Rodgers, who was to become director of the observatory in 1986. But he had chosen his topic before he even arrived – a study of nucleosynthesis in our galaxy. The theory that stars convert light elements into heavier ones via nuclear reactions had been worked out by Burbidge, Burbidge, Fowler and Hoyle in the 1950s. "That was the bible that showed the different elements come from different nuclear processes in different stars. And the question when I came on the scene was, is the result the same throughout the whole history of the galaxy, or is there evidence of secular, relative abundance evolution for elements produced by nuclear reactions under very different conditions?" Butcher wanted to measure differential chemical abundances in dwarf stars of r- and s-process elements, which are produced in different stars and over widely different timescales.

However, he soon discovered that the available gratings in the 74 inch Coude were not suitable for the work. With advice and help from Bessell and Rodgers he put together in the Coude one of the first high-resolution echelle spectrographs in astronomy (Butcher 1972, 1975a, b). "What I found," he said, "was, over a very large range of ages and over mean abundance levels differing by a factor of 30, basically there was very little or no measurable difference in the relative abundances. I thought that was a problem for the concept of stellar nucleosynthesis being a vigorous, ongoing phenomenon in the galaxy."

This approach to doing research, of developing new instrumental capabilities to make new observations possible, characterized Butcher's professional career. On a visit to Mount Stromlo in 1973, Peter Strittmatter from the University of Arizona in Tucson offered him a job following his thesis defence. Butcher left Mount Stromlo in 1974 to work at the Steward Observatory as a Bart Bok Fellow. While in Tucson he became friends with Gus Oemler and Roger Lynds at the Kitt Peak National Observatory, eventually joining them on the Kitt Peak staff. Lynds had a particular interest in the new panoramic digital detectors and was kind enough to involve Butcher in testing and implementing them on the telescope.

Oemler interested him in trying to observe the evolution of galaxies over cosmic time. They decided to try to use the new digital detectors to look at rich galaxy clusters, which were ideal targets for the relatively small fields of view of these early vidicon and CCD devices. "It is hard to appreciate today that in the 1970s received wisdom was that galaxies formed early and essentially didn't evolve visibly over recent cosmic time," said Butcher. But he thought S0 galaxies (which are disc systems without any current star formation) might just be very old spiral galaxies in which the gas had all been converted into stars. Oemler felt that might be the case, but that probably in clusters their gas gets stripped away by the ambient cluster medium.

To try to test the two hypotheses for the origin of S0 galaxies, they used the new detectors to observe what was happening. "And lo and behold, we found lots of blue galaxies in clusters at modest redshifts, which shouldn't have been there according to all the then current ideas. Some of the galaxies had changed dramatically in recent cosmological times,"(Butcher and Oemler 1978, 1984). Senior astronomers were scathing about the claim, dubbed the Butcher–Oemler effect. "If you had an effect named after you, that tended to mean that nobody believed it and it wasn't going to turn out to be correct in the long run. So it was not a positive thing to have a Butcher–Oemler effect at that time. It was an unpleasant period in my life."

In the early 1980s, Barry Newell at Mount Stromlo teamed up with PhD scholar Warrick Couch to study a dozen high-redshift galaxies, taking the photometry from deep photographic plates mostly from the Anglo-Australian Telescope at Siding Spring Observatory. According to Couch, this work "made the very important step of independently confirming the Butcher–Oemler effect and showing it to be widespread and hence generally a universal property of rich, centrally concentrated clusters at redshifts beyond 0.2", (Couch 2006 pers. comm.)

Butcher said that further confirmation came several years later: "Gus Oemler found that Zwicky had noted the phenomenon visually on his photographic plates from Palomar. Zwicky has often been right, so that gave me courage to continue to lobby our colleagues about the reality of the evolution." Today, undergraduate textbooks include the Butcher–Oemler effect.

Butcher stayed at Kitt Peak for about seven years. While there, he worked to perfect CCD detector systems and spearheaded their use for imaging and multi-aperture spectroscopy for observing very faint high-redshift galaxies. He was also project scientist for several new observing instruments including an early spectrograph for obtaining spatially resolved spectra at resolutions approaching the diffraction limit.

By 1983, Butcher had moved to a position at Kitt Peak where he was influential in determining policy, but even so decided it was time to try something new. By chance, the Dutch became interested in his expertise as an astronomical instrumentalist. "I was asked to consider a job in the Netherlands specifically to help out in a collaboration with the UK to build a new observatory on La Palma in the Canary Islands. So my instrumentation background was what motivated them to offer me a professorship at the Groningen University." Groningen has long had a strong reputation in astronomy. In the early part of the 20th century, J C Kapteyn was at Groningen and a strong advocate for travelling to the very best overseas observatories to take the highest quality data, which would then be analysed at home. This is a common enough approach today but was unusual for the time. It was only after the second world war, when Dutch astronomers moved into radio astronomy, that they could observe the skies seriously from the Netherlands itself.

Long-term planning

Butcher was to live in Netherlands for more than 25 years, taking up Dutch citizenship. Dutch forthrightness was initially a shock, but after a while "you begin to really appreciate that, because there are generally no hidden agendas". He was also impressed with the way the Dutch do things. "The Dutch think in the long term. So whether they're organizing the country or their science, they don't think of the next two years, they think of the next 10 to 20 years. I found that very attractive."

Shortly after he arrived at Groningen, a solar physics group reported the first observations of global oscillation modes in the nearby star α Centauri, which indicated significant departure from model predictions. If correct, this would have consequences for the then open solar neutrino problem, as well as age estimates for stars, the galaxy and possibly the universe. Such global oscillations in the Sun are excited by convection and the equivalent on other stars held out a promise of being able actually to measure the interior structures and evolutionary stages for individual stars. Here was a chance to build on work done for La Palma with the Queensgate Instruments company, to develop a very stable Fabry–Pérot and design and implement one of the first stellar seismometers (Butcher and Hicks 1986). Observations with the 3.6 m European Southern Observatory telescope on Cerro La Silla, Chile, were compared with model predictions for α Centauri and found to be in agreement (Pottasch 1992). In the meantime, the solar neutrino problem was resolved with new neutrino physics rather than the structure of the Sun. Butcher decided to move on to other investigations.

In Groningen, Butcher also explored the possibility of using stellar abundances to develop a radioactivity chronometer for the galaxy. "The idea was to see whether I couldn't find a long-lived radioactive element that I could measure. The galaxy was thought at the time to be over 15 Gyr old, so I needed an atomic species having a single unstable isotope with a comparable half-life with which to develop a chronometer, with thorium being the obvious choice." He used the sensitive Coude spectrograph at the 3.6 m telescope at ESO La Silla to measure its abundance relative to stable elements in stars of different ages (Butcher 1987). He did not find any variation over the age range of his sample stars, and concluded that perhaps the galaxy was rather younger than people in stellar evolutionary circles had been thinking. In the mid-1980s, Butcher became involved at ESO with developing the scientific specifications for what would become the Very Large Telescope. The design of an efficient, high-resolution stellar spectrograph was a major challenge and led to the development in Groningen of an innovative prototype instrument, later called FRINGHE, a heterodyned holographic spectrometer (Douglas *et al.* 1990). "The idea was to image the Fourier transform of the spectrum onto a two-dimensional CCD detector, thereby to gain both throughput (Jacquinot) and multiplex (Fellgett) advantages. It was a way of making a cheap, quite high-resolution spectrometer for the VLT." They tested the concept and it worked well. But the available detectors were relatively small, so the wavelength coverage that one could achieve in a single integration was also limited. In the end, ESO chose a conventional, much more expensive solution, UVES, giving wider wavelength coverage.

By 1991 he was again looking for a change, but with his family settled in the Netherlands the options were limited. As chance would have it, he was then offered the directorship of Netherlands Foundation for Research in Astronomy (ASTRON), a government-financed institution in Dwingeloo that specialized in radio astronomy but was starting to develop visible-light instrumentation as well. He would spend the next 16 years managing ASTRON.

Dutch astronomers were divided at the time as to whether future investments should focus on optical astronomy using facilities at La Palma and ESO, or on radio astronomy, which would at least allow new forefront facilities to be located in the country. The compromise reached was for modest investments in both. In fact, the idea of the Square Kilometre Array came under serious discussion in 1993 and Butcher ensured that Dutch R&D at ASTRON would focus on the necessary technologies and scientific development. These included the development of aperture and focal plane phased array detection, new correlator approaches, and a long-term enhancement programme for the Westerbork radio telescope. "In truth, I knew nothing about radio astronomy. The successes at ASTRON during my directorship are proof that when directors support their best people, really good things happen."

One of the major outcomes of the ASTRON programme was the Low Frequency Array (LOFAR), one of the world's largest radio telescopes having sensitivity in the frequency domain 15 to 240 MHz, where the ionosphere causes major imaging difficulties. "The problem with conventional radio telescopes has been that much of the cost is in the steel of the giant dishes that move. The cost of steel is not going down with time, so such mechanical systems are and will stay very expensive." Jan Noordam and Jaap Bregman pointed the way to the solution, and LOFAR follows their advice, whereby the

1: The LOFAR superterp with six LOFAR stations on it. Terp means artificial hill and, at 340 m across, this is the largest of the Dutch sites. (Top-Foto, Assen)

costs are shifted towards electronics and software. "That means," said Butcher, "because of Moore's Law, it'll get cheaper with time rather than more expensive. And so the idea was to build a telescope with no moving parts, in which the pointing and focusing is done in software, and with the antennae very low to the ground to mitigate the RFI [radio frequency interference]. The resulting instrument becomes much less expensive than conventional designs." Indeed, the cost and the use of new technology in a pathfinder for the SKA was a major motivation to build the telescope, although it is also making high-quality observations at these frequencies possible for the first time (Butcher 2004). Most of the antennae are in the Netherlands, although now there are others scattered across Europe.

The telescope has an ambitious science programme in four fundamental applications: the epoch of reionization; extragalactic surveys and their exploitation to study the formation and evolution of clusters, galaxies and black holes; transient sources and their association with high-energy objects such as gamma-ray bursts; and cosmic-ray showers and their exploitation to study the origin of ultra-high-energy cosmic rays (Rottgering 2006). The science that motivated Butcher himself was observing the first luminous objects in the early universe.

Extending LOFAR

A fascinating spin-off from the LOFAR project was suggested by an undergraduate student at the Delft University of Technology. This happened when Butcher was going round the Netherlands telling people about LOFAR. "Following my talk in Delft, an undergraduate student there, Gerrit Toxopeus, put up his hand and said: 'What you're talking about here is a data transport network that connects all these antennas. Why can't you connect other kinds of sensors onto your network too?' This simple question led to the inclusion of geophones, to study remaining pockets of natural gas in the underground near the telescope; sensor arrays for improving agriculture in the region; and infrasound sensors for acoustic imaging of the atmosphere. LOFAR became not only a radio telescope but also a scientific instrument that used the infrastructure for all kinds of really interesting projects. Toxopeus now has a PhD and is working for Norsk Hydro."

Butcher received a Knighthood in the Order of the Netherlands Lion in 2005 for the interdisciplinary science, innovation and public outreach achieved with LOFAR. So should we address him as Sir Harvey? "No, the Dutch don't do that. You get a tiny little pin and that's it."

Almost 33 years after he finished his PhD at the Research School at Mount Stromlo, Butcher returned as its director. The observatory had been devastated in bush fires in 2003. His predecessor as director, Penny Sackett, had done an excellent job in organizing the reconstruction of the main buildings before she left to become Australia's Chief Scientist. Now it was time to focus on strategy. Butcher had three things in mind when he arrived in 2007. "One was to strengthen the academic programme so that really smart young people would want to come to Mount Stromlo again." He did this in particular by appointing high-profile postdoctoral fellows and mid-career researchers, but also by convincing the university and government to finance participation in the Giant Magellan Telescope (GMT). This ambition was, of course, also boosted by Brian Schmidt's Nobel Prize for Physics in 2011. Next in priority was engineering. With his long experience in technology management, Butcher revitalized the engineering group and vigorously pursued opportunities for building instruments for the GMT. A new wing of the Advanced Instrumentation Technology Centre (AITC) was completed. His third objective was to build on the heritage status of the Mount Stromlo site to increase the programme of public outreach, ultimately to include a space and astronomy museum on site. However, this goal for a museum at Mt Stromlo has not yet been realized.

Butcher had a good run in his directorship of Mount Stromlo. According to Ken Freeman, a senior member of the academic staff at the observatory, "he left Stromlo stronger than he found it. The place is scientifically more vibrant than it was, and the morale is generally very good." He got Mount Stromlo into adaptive optics with several strategic appointments. He promoted the observatory becoming involved in space research, an area that the Australian government wants the country to move into. ●

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Future exploration of t

Missions to the frigid outer reaches of our solar system present significant technological challenges, but there remains a breathtaking scope for new and exciting discoveries. Leigh Fletcher reports on an RAS meeting that demonstrated a host of innovative ideas to explore the giant planets.

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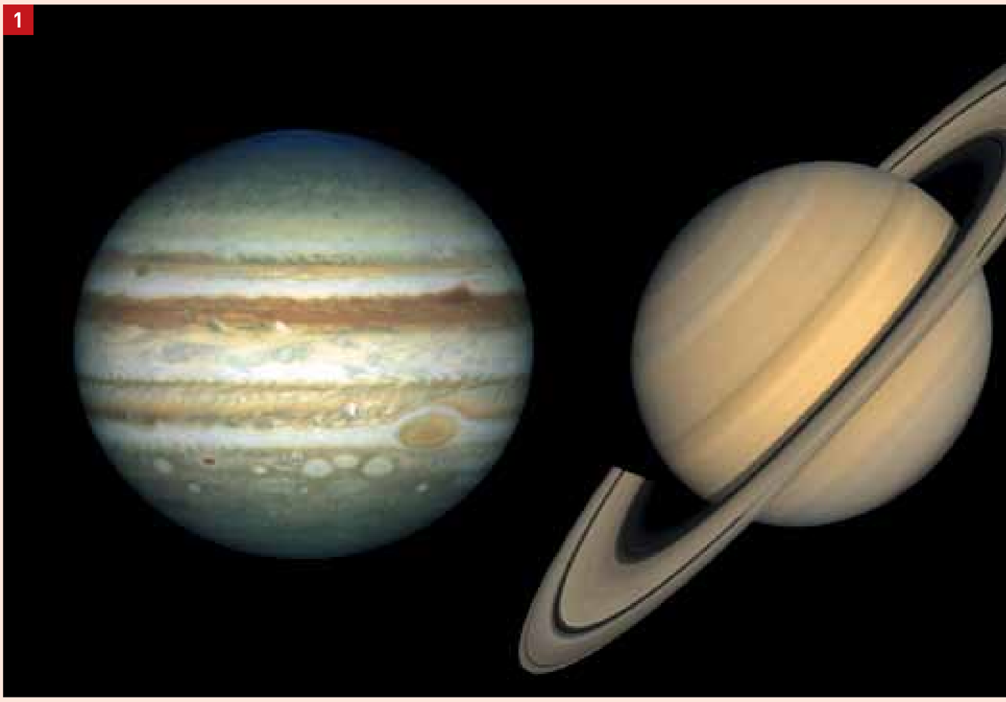

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Exploration of the giant planets of our solar system over the past few decades has revealed four unique, complex and dynamic worlds (figure 1). Jupiter, Saturn, Uranus and Neptune have deep fluid interiors, gaseous atmospheres and extended magnetospheres, which serve as natural planetary-scale laboratories for the fundamental physical and chemical processes at work throughout our galaxy. Their bulk compositions and internal structures provide signatures of the conditions within our solar nebula during the epoch of planet formation. Each harbours a complex system of planetary rings and a diverse collection of satellite environments, some with deep hidden oceans that may be of astrobiological importance. And although our understanding of these systems remains in its infancy, the four giants serve as templates for the interpretation of exoplanetary systems being discovered throughout our galaxy. The scope for new discoveries in this vast region beyond Mars is enormous, and there is no shortage of exciting mission concepts.

The RAS hosted a Specialist Discussion Meeting "Future exploration of the outer planets" on 14 December 2012 to bring together experts in giant planet systems to identify the key science questions and technological challenges of future exploration of the outer solar system. The meeting was broadly divided into two sections, beginning with discussions of future exploration of the ice giants Uranus and Neptune, visited only once by Voyager 2 almost a quarter-century ago, before returning to the more massive gas giants Jupiter and Saturn. All presentations were invited, with three keynote speakers.

Leigh Fletcher (University of Oxford) opened the meeting with the rationale for outer planet exploration described above, and went on to highlight recent discoveries that show that the giant planets are not the static unchanging worlds we sometimes imagine them to be.

he outer solar system

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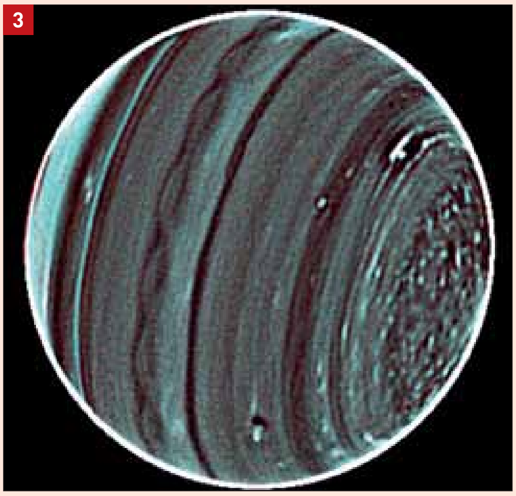


1: The four giant planets shown to the same scale using images from Voyager (Earth is about a quarter of the size of Neptune). Hydrogen and helium gases are the dominant constituents, but the larger proportions of heavier molecules in Uranus and Neptune distinguish the two "ice giants" from the larger "gas giants", Jupiter and Saturn. (NASA/Lunar and Planetary Institute)
2: Cassini true-colour image of Titan's forming south-polar vortex on 27 June 2012, with a scale of 3 km per pixel. Clouds appear around the edge of the vortex, with potential subsidence in the centre of the convection cell. (NASA/JPL-Caltech/Space Science Institute)
3: Uranus revealed in unprecedented detail in July 2012 by the Keck telescope. Rotational smear and the effects of zonal wind patterns were removed and more than 100 near-infrared images were stacked, revealing the atmospheric banding, convective clouds, waves and dynamics for the first time. (NASA/ESA/L A Sromovsky/P M Fry/H B Hammel/I de Pater/K A Rages)

Saturn passed the spring equinox in 2009; the northern hemispheres of the planet and its satellites are emerging into spring sunlight after 15 Earth-years (half a saturnian year) shrouded in winter darkness. This seasonal shift in sunlight is having dramatic effects on the atmospheres of Saturn and Titan as observed by the Cassini spacecraft, with the emergence of a giant planet-encircling storm in Saturn's troposphere in 2010; the illumination of a swirling polar cyclone within a bizarre hexagonal wave at Saturn's north pole; and the birth of a polar vortex at Titan's south pole as winter approaches (figure 2). Improvements in adaptive optics imaging techniques on giant ground-based observatories has revealed the turbulent weather of the ice giants, with bright convective features appearing in storm bands, powered by internal heat, despite their great distance from the Sun. These include the sharpest images of Uranus ever observed (figure 3), showing a dramatic scalloped wave around the equator, discrete convective clouds and turbulent activity at the poles. And not to be outdone, video capture techniques employed on a daily basis by amateur observers of Jupiter have revealed the frequency of impacts into the giant planet, the most spectacular occurring in 2009 and generating an ocean-sized area of dark debris above the cloud tops. Furthermore, Jupiter is now coming to the end of a global-scale upheaval in its banded structure, which started with the whitening and subsequent re-emergence of the dark-brown South Equatorial Belt in 2009–10. The taxonomy and phenomenology of this intense activity on all four giants are only beginning to be understood, and the underlying forces deep beneath the clouds have yet to be revealed.

Giants of ice

Mark Hofstadter (NASA/JPL) gave the first keynote lecture of the day, describing the prospects for a NASA-led mission to explore an ice giant. Opening with a Dickens quote, he described ice giant science today as the best of times (because the 2009 US decadal survey of planetary science acknowledged the importance of a future large flagship mission to an ice giant) and the worst of times (because flagship-scale missions seem a remote possibility given the current state of the planetary science budget). Nevertheless, ice giant exploration appears as a gaping hole in the space programme, because they were visited only once by Voyager 2 in 1986 (Uranus) and 1989 (Neptune). Ice giants are fundamentally different from any other environment found in the solar system, and there is much that we don't understand, yet the Kepler sample of planets around other stars hint that Neptune-sized worlds might be commonplace in our galaxy, possibly more abundant than terrestrial-sized planets. US scientists are therefore keen to work with their international colleagues to develop mission concepts for the ice giants, in the hope that we can pool our resources to see a mission fly before a half-century passes since the groundbreaking Voyager mission. Of the two, Uranus is the easier target to reach, which reduces overall mission cost. And its bizarre planetary tilt (98° to the ecliptic plane, the largest of any planet) challenges our understanding of planetary formation and evolution in ways the other planets do not. In fact, no Uranus formation model is consistent with all the available constraints (gravity and magnetic fields, bulk composition, heat flux and planetary temperature).

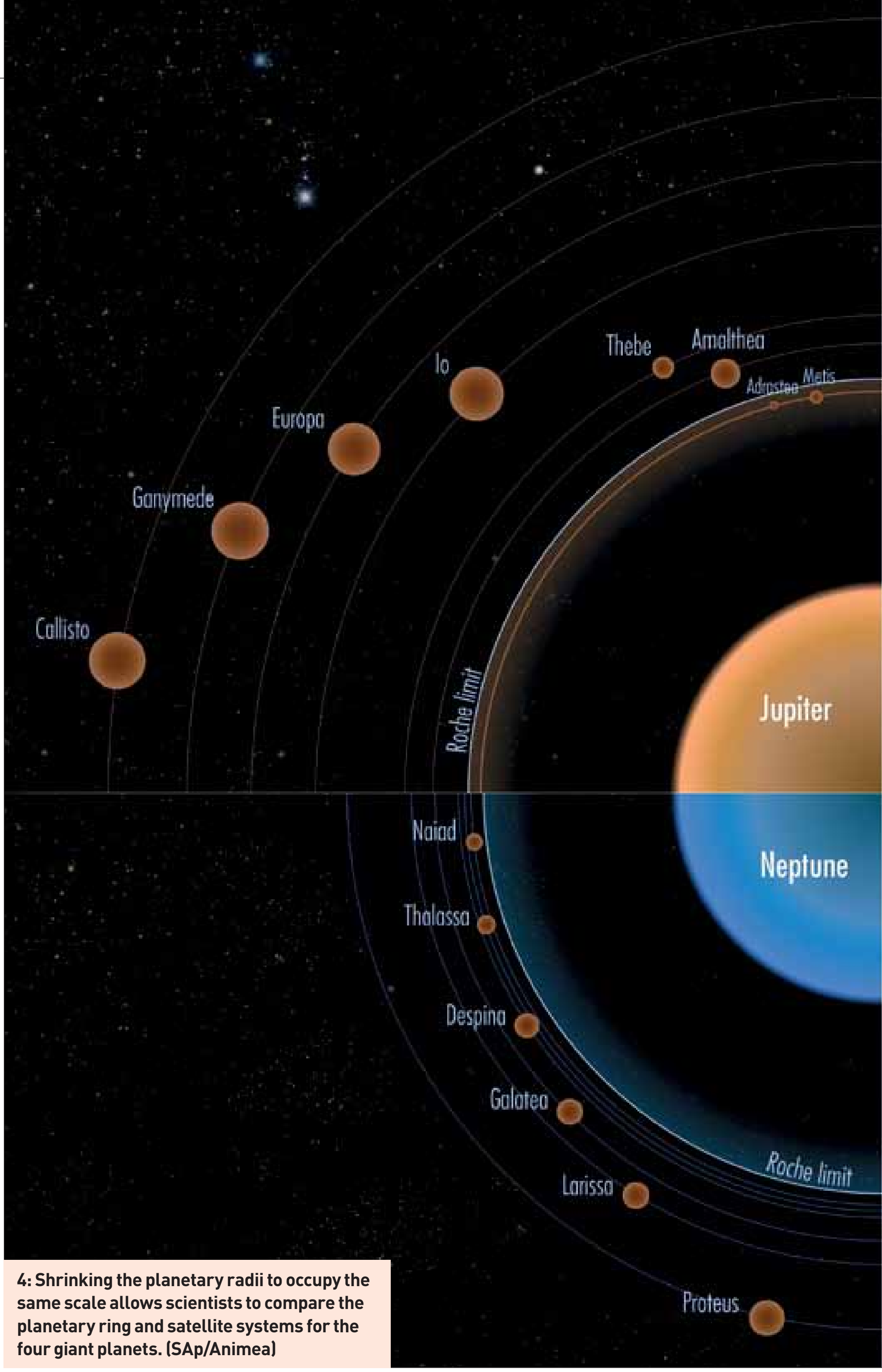
Indeed, scientists have a long wish list of questions to be answered about Uranus, including revealing its internal fluid structure and bulk composition to understand why ice giants differ substantially from the larger gas giants, along with a suite of objectives concerning the planet's atmosphere (climate and apparently sluggish weather), the highly asymmetric magnetic field, interior dynamo and energy budget, as well as studies of the geophysics of the satellites (figure 4) and the dynamics of the uranian rings.

For all these reasons, a US-led mission to Uranus was seen as a high priority for a flagship mission (i.e. a Cassini-scale mission costing in excess of $1 bn), once missions to return martian soil samples and explore the icy oceans of Europa have been flown. But in reality such a flagship might still be 20 to 30 years away, so the audience discussed the viability of smaller-scale US missions (falling under the New Frontiers $0.5–1.0 bn envelope like the Juno Jupiter mission, or even Discovery-class missions for less than $0.5 bn, like the Mars InSight mission) to achieve a small subset of these research aims. However, an ice giant mission would be the chance of a generation, so the audience agreed that international collaboration would be required to ensure that we could achieve science of the highest possible quality at this destination. So the mission studies will continue, along with relevant technology development (entry probes, solar power, radioactive power sources) and a high rate of ice giant science from Earth-based observatories, to ensure that a mission to Uranus remains a high priority and a realistic aim for solar system science.

Following directly from the US perspective on ice giant missions, **Chris Arridge** (MSSL) described an ambitious European mission to Uranus that was proposed to ESA as a medium-class mission in 2010: Uranus Pathfinder. This orbital mission concept was not selected but remained highly rated and had the support of 165 scientists across 13 countries, and addressed questions at the heart of Europe's "Cosmic Vision". In particular, Arridge described the importance of studying a magnetosphere whose poles point into the solar wind at solstice, as opposed to the terrestrial magnetosphere whose poles remain approximately perpendicular to the solar wind at all times. Indeed, this could be our only way of studying terrestrial magnetospheres of the distant past, for example during Earth's magnetic field reversals. Uranus Pathfinder was to study this unusual magnetic field configuration, along with the satellites, rings and ice giant atmosphere/interior in unprecedented detail. The spacecraft was to be launched by Soyuz in 2021, using chemical propulsion to reach Uranus orbital insertion in 2037, five decades after Voyager 2. The orbital phase was limited by the poor knowledge of hazardous material within the ring plane, but was to be a polar orbit for interior and magnetic field studies. The orbiter reused the Mars Express and Rosetta platforms, three-axis stabilized using reaction wheels and thrusters during the orbital tour. Because 400 m^2 of solar panels would be required to provide enough energy at the distance of Uranus, Pathfinder instead used radioisotope power sources based on the decay of americium rather than plutonium. The thermal requirements of a Uranus mission are extremely challenging, given the need for high-temperature Venus gravity assists before reaching the frigid uranian system. Instruments included cameras and remote-sensing devices in the infrared and UV, along with plasma, particle and magnetic field experiments, and concepts including an atmospheric entry probe were also explored. Despite the deselection of the Uranus Pathfinder mission, the development process has ignited the European community to further explore the prospects for small, focused missions capable of addressing outer solar system science goals, while preparing for a large-class ice giant mission in the coming decades.

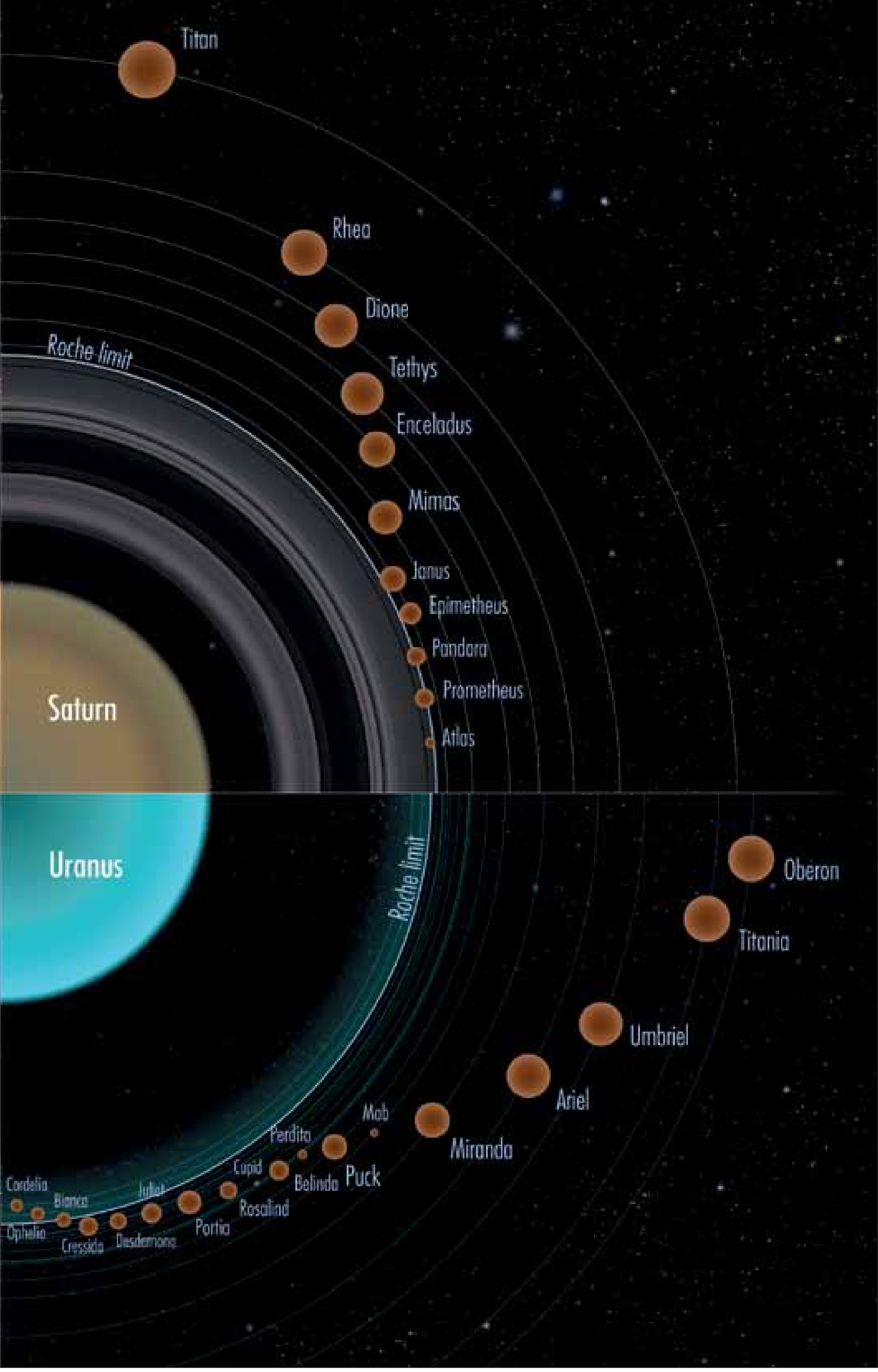
Planetary light shows

Tom Stallard (University of Leicester) followed with the current status of ionospheric and auroral studies for the four giant planets, showing that we're presently at the limit of what can be done without spacecraft. The presentation highlighted the extreme contrast between the gas and ice giants. Hubble and Cassini movies of the auroral displays on Jupiter and Saturn show complex auroral emissions, providing direct information about currents flowing into the polar regions and the shape of the internal fields, along with the footprints of material funnelled by the magnetic field lines from individual satellites into the polar ionosphere. On the other hand, we have had only one detection of auroral features on Uranus, by Laurent Lamy and colleagues, and no signals at all from Neptune. Researchers use the infrared emission of H_3^+, an ion emitting in a region where atmospheric methane blocks out the bulk of reflected sunlight, to detect aurora and measure atmospheric temperatures, and find that the upper atmospheres of all four giants are significantly hotter than would be expected from heating by sunlight alone. This conundrum, known as the "energy crisis", hints at an as-yet undiscovered process responsible for this extreme heating of the upper atmospheres. Furthermore, ground-based observations over 15 years have suggested that the Uranus H_3^+ emission temperature is slowly dropping, by hundreds of Kelvin. The cause may be seasonal, but high-resolution close-in studies of Uranus are required to understand this bizarre observation.



4: Shrinking the planetary radii to occupy the same scale allows scientists to compare the planetary ring and satellite systems for the four giant planets. (SAp/Animea)

The infrared light-gathering capabilities of the James Webb Space Telescope (JWST) have the potential to revolutionize these studies, although it will only be able to look at very small regions of Jupiter and Saturn in a single instant. But, for now, auroral attention is focused on NASA's Juno mission, due to arrive at Jupiter in 2016 for a one-year polar science mission. With



UV and infrared instruments, Juno will provide high-resolution views of Jupiter's aurora. Additionally, Juno will map Jupiter's gravitational field to constrain its internal structure, and use a microwave sounder to peer beneath the jovian cloud decks for the first time. Juno is the only spacecraft currently en route to a giant planet, and will end its life at approximately the same time as Cassini (late 2017), leaving the giant planets without any visiting spacecraft until the next generation of missions are funded and developed (e.g. JUICE, see below).

Origins of ice giants

Olivier Mousis (Toulouse) provided the second keynote lecture of the day, describing theories and testable hypotheses for the origins of Uranus and its satellite system. A collision with an impactor (maybe twice the size of the Earth) early in the history of the solar system remains the best theory explaining the extreme tilt of Uranus, and the subsequent formation of the satellites in the impact-generated debris disc (i.e. a mix of the impactor and the proto-Uranus). Alternative ideas suggesting that the axial tilt was caused during the outward planetary migration phase due to a large additional uranian satellite do not seem to agree with existing satellite formation scenarios. Assuming that giant impact hypothesis, Mousis presented two extreme cases: one where the Uranus subnebula contains very little water (the gas is mostly hydrogen from the proto-Uranus), and another where the disc is dominated by water from the original impactor. A model was used to predict the condensation and trapping of materials in icy grains and accretion to form the planetesimals, which went on to form the uranian satellites. The result was two different satellite compositions, depending upon the water-rich or water-poor assumption. If the isotopic composition (specifically the amount of deuterium) in the ices could be measured by a mass spectrometer (e.g. ices sputtered into orbit from the satellite surface), then we would be able to distinguish between satellite formation from the water-rich impactor material, or satellite formation from the water-poor material ejected from the envelope of the proto-Uranus. This *in situ* measurement could have the effect of telling us where the icy planetesimals that accreted into Uranus and the impactor originally came from (e.g. from the formation region of the giant planets, or from the outer domain of icy comets).

The formation of the giant planets themselves was a crucial epoch in the history of our solar system evolution, and the ratios between different elemental and isotopic abundances provides clues to the chemical make-up and origins of the planetesimals forming these planets. Some elemental enrichments, such as the amount of carbon or deuterium, can be derived using infrared remote sensing, but others require *in situ* sampling via entry probes. The noble gases and oxygen are the best examples: Ne, Ar, Kr and Xe have no spectral signatures, and O is locked away in deep clouds of water. The Galileo probe remains the only *in situ* measurement of a giant planet to date, and sampled a region of Jupiter of unusual meteorology that had depleted the atmosphere of its volatiles. To understand how and where these planets formed, multiple small entry probes are required, both for different regions of the atmosphere and also for an inter-comparison of the planets. Developing the technologies required for *in situ* probes should be a key priority for NASA and ESA, with potential to achieve these measurements under New Frontiers or M-class cost envelopes (i.e. without the need for flagship-level funding).

Future technologies

The morning concluded with two presentations on the technology developments required to achieve the future exploration of the outer solar system. The challenges of reaching the distant outer planets mean that we may see only one in a generation. The missions must be long-lived to traverse the immense distances, with financial implications for maintaining teams of scientists and engineers throughout the mission lifetime. Chemical propulsion remains the method of choice, but new technologies combining solar and chemical propulsion, or electric propulsion using nuclear power sources, may

shorten these journey times. Power generation is crucial, with solar panel technology sufficient for jovian exploration (e.g. solar panels are used on Juno and the proposed JUICE mission to Jupiter). Radioisotope power sources (RPSs) offer increased capability and greater mission flexibility when exploring the outer solar system or more inhospitable environments where insolation is limited. RPS systems offer mission longevity, which can translate into greater scientific value for the cost of the mission. The European programme has focused on ^{241}Am as the isotope of choice for future RPS systems or radioisotope heater units (RHUs). The UK has unique resources on which to build an independent European capability in space nuclear power (using ^{241}Am) at a cost-effective and fast pace. Part of the UK's stored civil plutonium will be used to produce ^{241}Am. Suitable amounts of ingrown americium are present as a result of it originally containing ^{241}Pu, which decayed into ^{241}Am during its considerable time in storage.

Sophisticated thermal protection is needed to withstand the contrasts between baking Venus and icy Neptune, with more advanced technology required for *in situ* probes and aerocapture techniques. Radiation protection is required for any mission exploring the jovian system, to shield the sensitive instruments from the harsh environment of Jupiter's radiation belts. Maximizing the science return from a suite of instruments means ensuring that as much information as possible is returned (downlinked) back to Earth, requiring updates and investment in our deep-space communications systems. Finally, there is a continual push for miniaturization of components, so that more payload mass can be delivered for a particular mass of chemical fuel.

Richard Ambrosi (University of Leicester) reported on the long-term ESA project to develop a European radioactive power source based on americium. This is part of an industry–academic collaboration that includes: University of Leicester, Astrium UK, UK's National Nuclear Laboratory and System Engineering and Assessment Ltd (SEA) as well as numerous other institutions in the UK and Europe. The presence of americium in the stored, separated civil plutonium in the UK, makes it a viable option for future power sources. The key is to maximize the ability of the system to convert efficiently the radiogenic decay heat of americium into electric power. An important measure of this overall system performance is the specific power (measured as Watts per kilogramme of system mass). A proof of concept electrically heated laboratory RPS is currently being tested with the aim of disseminating the results later in 2013. It is hoped that flight systems will be in development by 2016. A team at the UK's National Nuclear Laboratory is actively working on the extraction of ^{241}Am from the separated civil plutonium stored in the UK. SEA is leading a team working on a Stirling engine system for power generation. The UK is currently the biggest contributor to this optional ESA programme, as it will be essential for future outer solar system exploration and particularly for a revision of the Uranus Pathfinder concept described earlier.

Matthew Stuttard (Astrium) presented some of the activities of Astrium with particular relevance to future outer solar system exploration. Over the past few decades Astrium has been the leading prime contractor for spacecraft development in Europe for planetary science, solar science, fundamental physics and astronomical missions (18 missions and telescopes in total). However, with the exception of Cassini–Huygens, the outer solar system (and specifically Jupiter) remains as a gap in their repertoire. The Jupiter Icy Moons Explorer (JUICE) mission (figure 5) was selected as ESA's first "L-class" mission in 2012 and presents many opportunities for UK industry, with spacecraft design concepts already being prepared by Astrium and UK leadership roles in some of the individual instruments to be carried along to Jupiter. Many of the challenges highlighted above will be pertinent to JUICE – miniaturization and payload accommodation trade studies to ensure the maximum scientific return from the payload mass; the use of solar power with 70 m^2 of panels weighing 280 kg; coping with Jupiter's harsh radiation using many kilogrammes of additional shielding; dealing with solar flux that is 60 times higher at Venus than at Jupiter; and attempting to downlink 1.4 Gbits of data per day from a spacecraft 36 light-minutes away. Furthermore, as the satellites of Jupiter (figure 4) may harbour habitable conditions, we must ensure that the spacecraft cannot contaminate these pristine environments (a requirement known as planetary protection). The 3.2 m high-gain antenna used for radio science and communication only just fits within the Ariane fairing, and a huge amount of propellant (3 tonnes) is required to carry the payload to Jupiter.

In addition to the JUICE design work, Stuttard also highlighted UK interests in penetrators – impactors for icy surfaces designed to address astrobiological and geophysical science goals. The UK has developed a niche based on the MoonLITE concept (a proposed British network of lunar penetrators to study the Moon's interior, structure and evolutionary history), and has formed a multidisciplinary community focusing on demonstrating robustness of these devices. Tests have already been performed with penetrators attached to a rocket sled at Pendine Sands, Wales. Further tests are planned in May 2013 with impacts into ice. As these studies move forward, penetrators would be a logical precursor for future surface exploration of moons such as Ganymede and Europa.

THE JUICE MISSION

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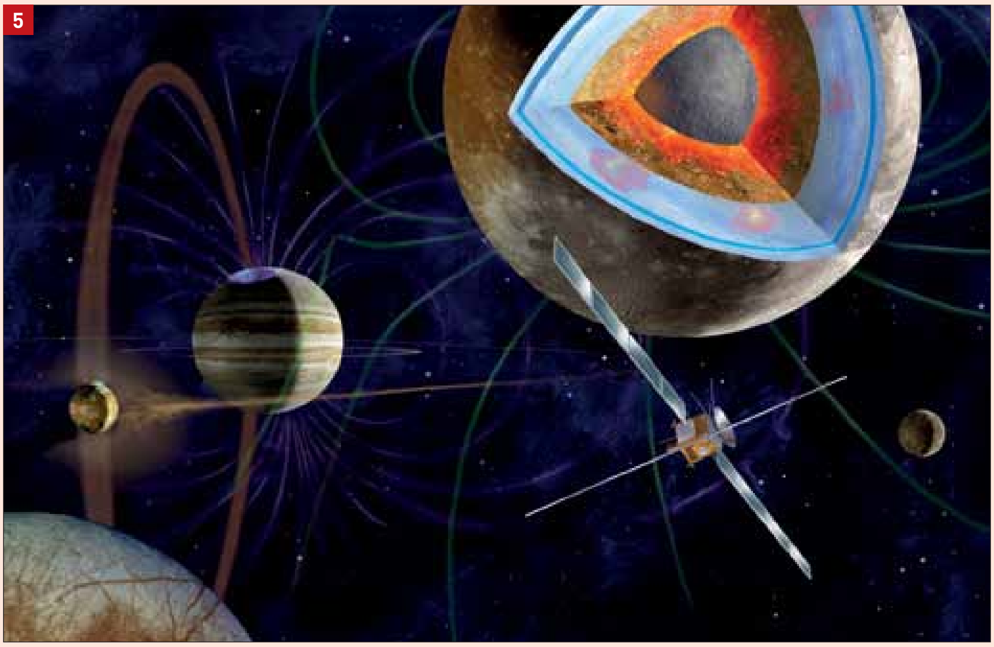

Habitable satellites

ESA's Cosmic Vision suggests that "the quest for evidence of life in the solar system must begin with an understanding of what makes a planet habitable". Life on Earth has been found to flourish in the most unlikely of places, proving its resilience to environmental conditions (e.g. the "black smokers" of Earth and their populations of extremophiles discovered in the 1980s). Once the Cassini and Juno missions cease in 2017, the hopes of the European giant-planet community rest with the next mission to the outer solar system, the Jupiter Icy Moons Explorer (JUICE, originally proposed as Laplace in 2007). This "large-class" ESA mission will use the jovian system to study the

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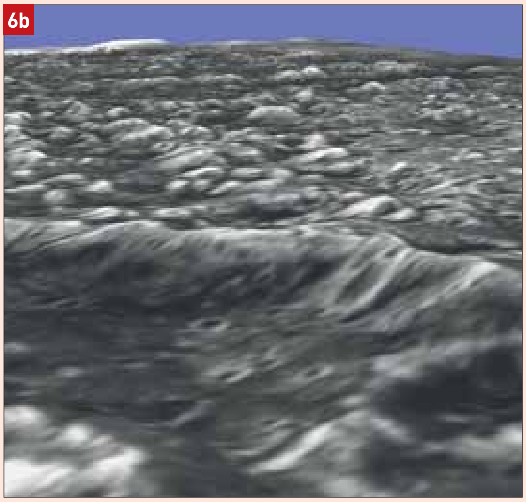


5: Artist's impression of the JUICE spacecraft in the jovian system, exploring Ganymede's surface and interior, the icy crust of Europa, and their connections via the magnetosphere to the gas giant itself. (ESA/M Carroll)
6: Ganymede, the largest moon in our solar system and the primary destination for JUICE. (a) Galileo false-colour image of Ganymede showing the different properties of surface regions (NASA/JPL). (b) Stereoscopic view of the Galileo Regio region of Ganymede, assembled from images taken by Galileo in 1996. (NASA/JPL)

emergence of habitable worlds around giant planets, and become the first spacecraft in history to orbit an icy moon. **Michele Dougherty** (Imperial) led the science study team responsible for defining the scientific goals of this Europe-led mission to Jupiter's moons, and provided our third keynote lecture of the day.

The three icy Galilean satellites are worlds of water, with icy crusts hiding deep oceans of water. The structures of these icy moons differ in their crustal thickness, the amount of energy provided by tidal flexing, and the connection between the liquid water and the satellites' silicate mantles. Ganymede (figure 6) is our best example of a liquid environment trapped between layers of ice, and Europa is our best example of liquids in contact with a silicate mantle. These "deep habitats" could potentially be abodes for extreme forms of life provided they have a source of energy, chemicals, a solvent (water) and longevity. If JUICE is able to prove that such conditions exist, this would push the habitable zone (the expected range of planetary conditions suitable for life) beyond Mars and into the outer solar system. Furthermore, these three "waterworlds" could be representative of a whole class of planetary objects around other stars, so JUICE will characterize their ice shells, oceans, global composition and surface evolution. The moons are connected to their planetary environment by tidal forces, and interact via the magnetosphere with the upper atmosphere of the gas giant. In addition, JUICE will study Jupiter's atmosphere, a perfect laboratory for planetary-scale fluid processes, and its magnetosphere, the largest particle accelerator in our solar system.

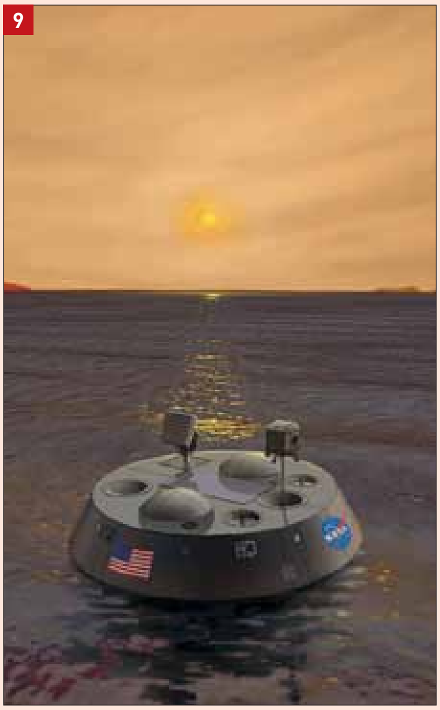
JUICE will carry a suite of instrumentation designed to reveal the jovian moons in unprecedented detail. These include high-resolution cameras, spectral imagers and sounders, fields and particles experiments for the jovian environment, and altimeters, ice-penetrating radars and radio science equipment to probe the icy crusts. Following a decade of development, JUICE will launch in 2022 for an eight-year cruise to Jupiter. After orbital insertion around Jupiter's equator in 2030, JUICE will execute a series of flybys of the Galilean satellites, from icy Europa to giant Ganymede and battered Callisto, while observing volcanic Io from a safe distance outside of Jupiter's harsh radiation environment. The two close flybys of Europa in 2031 have been designed to cover potentially active regions of the crust, where the morphology of features suggest relatively recent geologic activity and a thin icy crust, giving us our best chance of observing Europa's liquid ocean with radar. Further flybys of Ganymede and Callisto will help the spacecraft rise up out of the equatorial plane, revealing higher latitudes of Jupiter towards the polar regions, and sampling a broader range of astrophysical processes in the magnetodisc. Finally, in late 2032, JUICE will enter a polar orbit around Ganymede for the remainder of the mission, getting ever closer and closer to the satellite surface before a final crash to end the mission in 2033.

Potentially habitable environments are not restricted to the jovian satellites. Titan, Saturn's largest moon and the only satellite with a thick, smoggy atmosphere, has been extensively studied by the Cassini orbiter and Huygens probe (January 2005), yet **Mark Leese** (Open University) revealed the multitude of reasons why we should continue our exploration of this distant Earth-like moon. By the end of the Cassini mission in 2017, only a small percentage of Titan's surface will have been mapped at high resolution during the 60 or so hours that Cassini was close to the satellite. The nature of Titan's global methane cycle, seasonal lakes and river networks, dune fields, surface chemistry and potential cryovolcanism will remain mysterious. Given the thick atmosphere and liquid seas, there is no shortage of fascinating ideas for future exploration: ideas for surface probes and hot air balloons date back to the 1970s. TANDEM was an ambitious ESA-led mission proposed in 2007, consisting of an orbiter for Titan and Enceladus, penetrators for the icy moon Enceladus, a Montgolfier balloon and three entry probes for Titan. The Titan balloon (figure 7) would have sniffed the air and clouds and imaged the surface as it drifted around the planet, while the probes would have studied the composition and structure on the surface and searched for evidence of organics, making this a fascinating mission for astrobiology. TANDEM evolved and merged with NASA concepts to form the Titan Saturn System Mission (TSSM), which would have retained the Titan orbiter, a six-month balloon mission and one nine-hour lander, targeted at a northern lake for a short exploration. But this flagship-class mission was not selected, prompting scientists to consider more cost-effective exploration of the saturnian satellites.

The Titan Mare Explorer (TiME) was a Discovery-class (<\$0.5 bn) mission proposal to NASA to conduct the first exploration of an extraterrestrial sea using a lake lander (figure 9). It would have landed in the 300 km wide lake known as Ligeia Mare in 2023, during Titan's northern summertime conditions, to spend 96 days studying methane humidity, lake surface winds, liquid properties and depth, as well as taking photos of the descent and shoreline. The lander would have drifted around the lake by a few kilometres each day, moving in and out of outflow channels of river networks to study suspended sediments. At a slightly larger cost (New Frontiers class, \$0.5–1.0 bn), a lake probe would have landed in Kraken Mare (bigger than Earth's Caspian Sea) and featured a submersible element to sample the sediments at the bottom of the lake. Alternatively, another mission proposal was the Aerial Vehicle for In Situ and Airborne Titan Reconnaissance (AVIATR), a radioisotope-powered aeroplane to study surface geology and atmospheric science (figure 8). The plane would have had a year lifespan and a wingspan of between 4 and 5 m, making good use of the lower gravity and higher density of air on Titan compared to the Earth. Sadly, none of these concepts have yet been selected, but they demonstrate the huge range of possibilities for future exploration.

Each of these missions would feature instruments capable of analysing the chemical composition of the surface or atmosphere directly.

HOW TO EXPLORE TITAN: ARTIST'S IMPRESSIONS



7: Concept for the Montgolfier balloon and lake lander as part of the Titan Saturn System Mission (TSSM). (NASA/ESA)
8: AVIATR (Aerial Vehicle for In-Situ and Airborne Titan Reconnaissance) is an aeroplane designed to make use of the low gravity and high density to fly through Titan's atmosphere. (M Malaska)
9: The Titan Mare Explorer (TiME) capsule would perform the first direct inspection of an ocean environment beyond Earth by landing in, and floating on, a methane–ethane sea on Saturn's largest moon. (Johns Hopkins Univ. Applied Physics Lab/Lockheed Martin)

Andrew Morse (Open University) gave an overview of this sort of instrumentation, showing how it can provide ground-truth for orbital remote-sensing studies and is often the highlight of any planetary mission, but has the disadvantage that it samples only one location for a short timescale. Atmospheric entry probes, such as Galileo (1995), Kronos (a 2007 proposal for an ESA mission to enter Saturn's atmosphere) and Huygens (2005) are designed to measure atmospheric properties, winds, cloud properties and chemical composition. Each featured a gas chromatograph to separate compounds and a mass spectrometer to identify them, and Morse revealed how the technology is now advancing to provide even higher-precision instruments using multi-bounce time-of-flight mass spectrometry (MBToF) and two-dimensional gas chromatography (GCxGC) to permit targeted detection of molecules and isotopes. The penetrators that may ultimately be used to explore the surface conditions on Europa, Ganymede or Enceladus have been tested with mass spectrometers as part of their payload, and have been able to survive the high impact speed of the projectiles.

Beautiful rings

For much of the day the meeting focused on exploration of the planets' atmospheres, magnetospheres and intriguing satellite systems, but **Carl Murray** (Queen Mary University of London) finished the day by comparing and contrasting the types of ring systems around each world. Jupiter's ring system is *diffuse and dusty*, with the main ring connected to dust from Metis and Adastrea and gossamer rings from moons like Amalthea and Thebe. Saturn's innermost D ring is of the same type, with regular corrugations from a spiral wave associated with a ring impact in the distant past. The Cassini mission has revealed that material from Enceladus is the source of Saturn's E ring. Uranus and Neptune also have dusty diffuse rings associated with their satellites. These diffuse rings are contrasted with the *narrow and dusty* rings at Saturn, Uranus and Neptune, produced by collisional dust and then shepherded by small satellites. The spirals and streamers shearing out of Saturn's F ring due to Prometheus is a good example, as are Uranus's narrow rings and Neptune's Le Verrier and Adams rings. A third type is the *dense and narrow* rings confined either by satellites (e.g. Uranus's epsilon ring confined by Cordelia and Ophelia; and Saturn's C ring with the Maxwell Gap) or by their own self-gravity. This is contrasted with the *arcs and clumps* observed in the jovian rings, Saturn's Encke gap, and the arcs in Neptune's Adams ring associated with resonances with the moon Galatea. Finally, the most obvious ring structures are the *dense and broad* rings found in the Saturn system. Saturn's B ring has a high optical depth and accounts for most of the mass of the system. Some of these rings feature spiral density waves due to small satellites; notable gaps due to larger satellites (such as the Cassini division with Mimas and the Encke Gap caused by Pan); and "propeller" disturbances caused by smaller moonlets.

Having reviewed these five different types of rings (diffuse and dusty; narrow and dusty; dense and narrow; arcs and clumps; dense and broad), Murray finished his presentation with a review of future measurements needed to understand planetary rings. These included studies of the time variability (clumping, spirals, propellers) in Jupiter and Saturn's rings; precise determination of Saturn's ring mass and evolution; and studying the unknown composition, long-term stability and anomalous motions within the rings of the ice giants. Indeed, as debris discs around planets may have been the material from which the satellites formed (see the keynote lecture by Mousis), they could be thought of as moon nurseries and as fascinating laboratories for the processes at work in circumstellar discs.

With tightening budgets and shifting priorities, the mood of the international outer solar system community has taken a downward turn in the past few years. It is recognized that these missions are extremely expensive because of the technological challenges and their longevity, but none of these hurdles are insurmountable if international collaboration is maintained. Ongoing excitement over the rich discoveries of Cassini, anticipation of new insights from Juno, and a continuous stream of ever-improving ground-based instrumentation has kept the fire alive, and there is no shortage of exciting new ideas for exploring the outer solar system. From ice giant orbiters and habitable satellite reconnaissance, to Titan lake landers and balloons, along with penetrators and entry probes, the scope for continuing our exploration of the outer solar system is enormous. There is still so much out there to discover and understand, and this meeting captured some of that optimism and enthusiasm. We'll get there, eventually. ●

Leigh Fletcher, University of Oxford.

Autumn MIST 2012

MEETING REPORT Robert Fear and Emma Woodfield report on the Autumn MIST meeting, concerning the solar wind; magnetospheres of planets and comets; ionospheres, thermospheres and mesospheres and how these regions connect.

The UK Magnetospheric, Ionospheric and Solar–Terrestrial Physics (MIST) community held its annual autumn meeting at the Royal Astronomical Society, Burlington House, on Friday 30 November. MIST holds two annual meetings – a one-day meeting in London in the autumn, and a multi-day spring meeting in parallel with the National Astronomy Meeting – as a forum for MIST science.

ULF waves

The meeting began with an invited talk by **Tim Horbury** (Imperial College London) who presented early results from instruments on board the CINEMA-1 CubeSat. TRIO-CINEMA (Triplet Ionospheric Observatory/CubeSat for Ions Neutrals Electrons and Magnetic fields) will ultimately be a constellation of four identical 10 × 10 × 30 cm satellites which will be used as a technology demonstrator and also to study space weather. Each satellite carries two science instruments: a particle instrument called STEIN (Supra-Themal Electron, Ion and Neutral atoms) and a magnetometer called MAGIC (Magnetometer from Imperial College). The spacecraft and STEIN instruments were designed at the University of California, Berkeley (UCB), and were built by UCB and Kyung Hee University, Seoul; MAGIC sensors for all four spacecraft were designed and built at Imperial. The design of MAGIC is very different from that of a fluxgate magnetometer (the type of magnetometer traditionally flown on magnetospheric missions); MAGIC is based on magnetoresistive technology which permits an extremely lightweight and low-power instrument suitable for CubeSat missions (Brown *et al*. 2012). The sensor weighs less than 15 g, the electronics are less than 150 g, and the power drawn is under 500 mW. MAGIC serves two purposes: it operates in a low-power, lower precision "attitude mode" to provide the spacecraft with attitude information, and a higher precision science mode which provides 10 vectors per second with 0.25 nT resolution.

The TRIO-CINEMA project has had a large student involvement at all three institutions, providing significant educational benefit through its development alone. Planned scientific uses of the data from STEIN and MAGIC include remote sensing of the radiation belts from below, by imaging energetic neutral particles formed by charge exchange, and the tracking of magnetospheric waves and transients from the solar wind to the Earth (in conjunction with space- and ground-based instrumentation above and below). The data provided by STEIN and MAGIC on all four CubeSats will complement existing and future instruments (e.g. Cluster, the Van Allen Probes, SWARM, ionospheric radars and ground-based magnetometers).

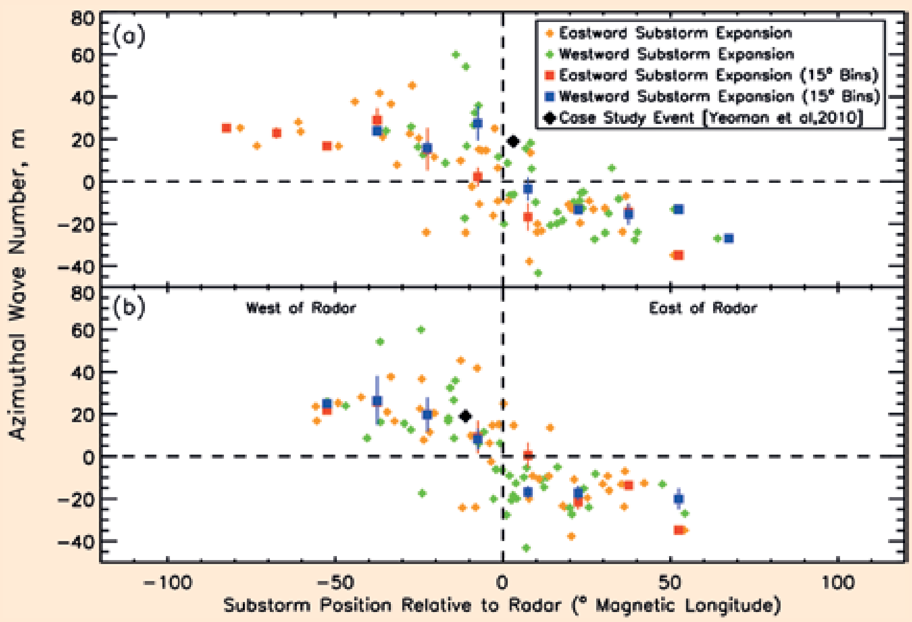
CINEMA-1 was launched on 13 September 2012, with the other three spacecraft due to follow in 2013. All four satellites piggy-back onto other launches, as is the norm for CubeSat missions. Magnetic field data from CINEMA-1 telemetered so far show good agreement with the International Geomagnetic Reference Field, indicating that MAGIC is operating as expected. So far, the only MAGIC data available is from the lower resolution "attitude" mode, but it does contain some evidence of the effects of high-latitude magnetospheric dynamics. Data are publicly available from the CINEMA website (http://sprg.ssl.berkeley.edu/cinema), and calibrated MAGIC data are available from the instrument team at Imperial College.

The morning session continued with three observational studies of ULF waves in different regions of the Earth's magnetospheric system, starting at the terrestrial foreshock with a presentation by **Luke Selzer** (University of Warwick). Plasmas are heated in the presence of quasi-parallel collisionless shocks, such as in supernova remnants, solar wind co-rotating interaction regions and in the foreshock immediately upstream of planetary bow shocks. Temperature anisotropies exist in such regions, which may lead to the plasma becoming unstable to small perturbations, which can in turn lead to the growth of waves. Recent observations in the solar wind have suggested a correlation between such instabilities and plasma heating, via the growth of waves. Selzer *et al.* presented observations from the Earth's foreshock – a region in which these processes can be observed directly with *in situ* measurements provided by the Cluster spacecraft. The temperature anisotropy ($T_\perp / T_\parallel$) was measured using data from the Cluster Ion Spectrometry instrument Hot Ion Analyser (CIS-HIA), and ULF waves were identified in data from the Cluster Fluxgate Magnetometer (FGM). The proton temperature was compared with the thresholds of several plasma instabilities (as a function of temperature anisotropy and plasma beta). Enhanced proton temperatures near the thresholds for the firehose instability in the presence of right-handed ULF waves indicate for the first time that plasma heating in the foreshock is associated with this instability. The authors proposed that this might indicate Landau damping by fast magnetosonic ULF waves.

It is well known that variations in the solar wind dynamic pressure can change dramatically the size of the Earth's magnetosphere, but the magnetosheath can also experience transient, large-amplitude pulses in the dynamic pressure that are not observed upstream in the solar wind. One means by which magnetosheath pressure pulses can be generated in the absence of solar wind pressure pulses is by the interaction between the bow shock and rotational discontinuities in the interplanetary magnetic field. **Martin Archer** (Imperial College London) presented a study into the magnetospheric impact of this type of pressure pulse. A series of magnetosheath pressure pulses was observed by two of the THEMIS spacecraft situated in the magnetosheath (THEMIS-D and E), and the pulses appeared to correlate well with upstream rotational discontinuities observed by the ACE satellite (although there were also cases where discontinuities were observed without a pressure pulse). The formation of pressure pulses at the bow shock was observed to deform the magnetopause downstream and cause ULF waves and low-frequency compressions of the magnetic field in the outer magnetosphere (THEMIS-A). The frequency of the magnetic field compressions was much lower than that of the sharp and impulsive magnetosheath pulses, indicating that the magnetopause acted as a low-pass filter. More detailed analysis revealed that pressure variations on timescales of a few minutes (corresponding to the Pc5-6 frequency bands) were able to penetrate into the magnetosphere. Magnetic compressions in this band were also observed by ground magnetometers at the times of the magnetosheath pressure pulses. The amplitude of the ground magnetometer signatures increased with magnetic latitude and location westward, and were observed to track westward at about 9 km s^{-1}. When this velocity was propagated back out to the magnetopause, there was good quantitative agreement with the expected westward motion of the intersection of the rotational discontinuity with the bow shock, as inferred from the solar wind measurements

(Archer *et al.* 2012).

Matt James (University of Leicester) reported on a statistical study of ULF waves driven by the injection of particles by substorms. Substorms were identified in global-scale images of the auroral region provided by the IMAGE satellite; data from five SuperDARN radars in Europe and North America were then examined for each of the substorm intervals, and 83 ULF waves were identified. It was found that the magnitude of the azimuthal wave number of the waves, $|m|$, increased with distance from the location of the substorm onset, with positive and negative values of m being observed eastward and westward of the substorm respectively, consistent with propagation of waves away from the substorm. The small number of waves bucking this trend were largely explained by the expansion of the substorms following onset (figure 1). The angular drift frequency, ω_d, was also found to be positive eastward and negative westward of the substorm, with $|\omega_d|$ decreasing with azimuthal distance from the substorm location to the radar. The inferred energy of the particles driving the ULF waves also decreased with azimuthal distance, which was explained as being due to the loss of high-energy particles into the loss cone before they can undergo gradient/curvature drift and drive waves further from the injection point. It was concluded that high-energy particles are able to drive low-m waves which are usually attributed to a source outside the magnetosphere (James *et al.* 2013).



1: The relationship between the azimuthal wave number of the ULF waves observed by SuperDARN radars and the location of the substorm relative to the radar (taken to be (a) the location of substorm onset and (b) the location of maximum auroral brightness during the substorm). The ULF waves are observed to propagate away from the substorm. (Reprinted by permission from John Wiley & Sons: James *et al.* 2013, The spatio-temporal characteristics of ULF waves driven by substorm injected particles *J. Geophys. Res.* in press)

Radiation belts

Following on from last year's highly successful Autumn MIST special session on the radiation belts and the exciting launch of the RBSP satellites, now called the Van Allen Probes, in 2012, **Richard Horne** (British Antarctic Survey, BAS) presented collaborative work within the SPACECAST project funded by EU Framework 7. High-energy (MeV) particles trapped in Earth's radiation belts can cause significant damage to satellites and are a real problem for manned spaceflight. Forecasting the level of hazard is difficult; the electron flux in the radiation belts can change by as much as 5 orders of magnitude in three minutes, for example.

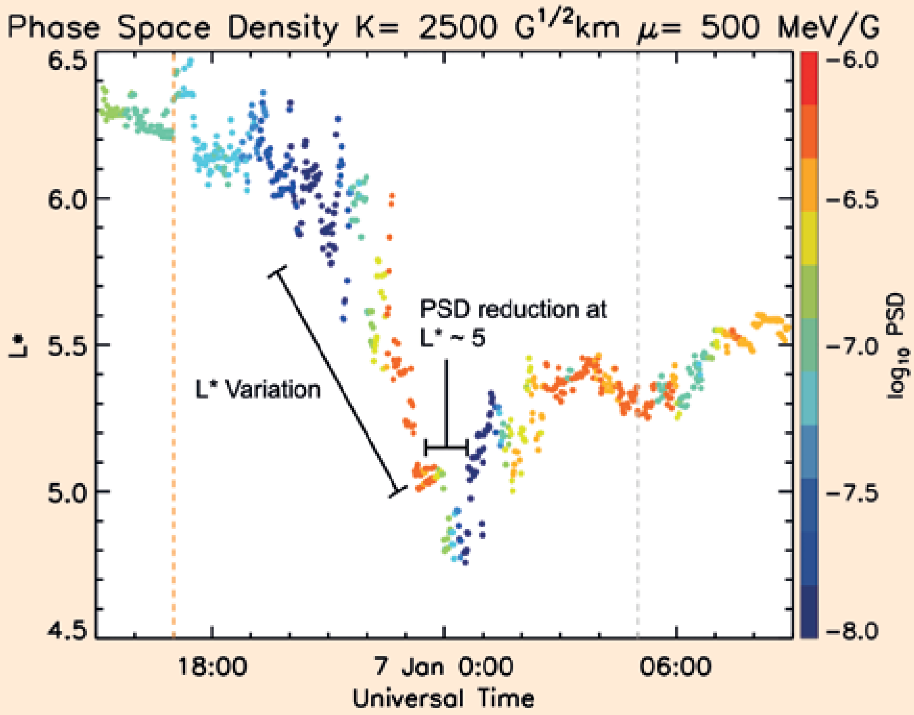
SPACECAST uses data from the ACE spacecraft in real time along with a forecast of *Kp* from the Swedish Institute of Space Physics and the British Geological Survey and data from Europe, Japan and the USA, to drive physical models of the radiation belts. Two independent models are run to produce forecasts: the BAS Radiation Belt model and the Salammbô model developed at the Aerospace Research Laboratory (ONERA) in Toulouse, France. Both models solve a diffusion equation to find the change in the electron phase space density, which is then converted into the electron differential flux. The models include radial diffusion (transport of electrons across the magnetic fields as a result of ULF wave activity) and wave–particle interactions that can cause both electron acceleration and loss. Initial results are promising; as part of the forecasting process, comparison is routinely made between predictions and the data observed by the primary GOES satellite. The SPACECAST forecast is output at http://fp7-spacecast.eu and is aimed at satellite operators, service providers, scientists and the general public.

The first of two talks investigating electron radiation belt dropouts was presented by **David Hartley** (Lancaster University). Using the MAGED instrument (Magnetospheric Electron Detector) on GOES-13, Hartley *et al.* used pitch-angle resolved electron fluxes with coincident geomagnetic field measurements to investigate electron dropouts during high speed streams (HSSs) in the solar wind. HSSs originate from coronal holes on the Sun; they show characteristic structure in the solar wind with a clear transition from slow to fast solar wind, density pulse and shear flow. HSSs are known to cause rapid decreases (dropouts) of flux in the electron radiation belt. Based on calculations of the phase space density for one case of an electron dropout (figure 2), Hartley *et al.* showed that primary losses attributed to outwards radial transport and possible magnetopause losses and secondary losses were enhanced by pitch angle scattering and atmospheric losses.

There has been little investigation of energetic ion composition in the outer radiation belt during HSSs, due mainly to the lack of data. Research has focused on the electron dropouts that occur during these times; the mechanisms are the subject of much debate. **David Forster** (Lancaster University) and co-workers used data from HSS-driven storm times for a superposed epoch study covering four days before and four days after the convection onset of the storm. They looked at H^+, He^+, He^{++} and O^+ ions between L shells of 4 and 7 R_E using data from the CRRES mission. The ratio of heavy ions to protons is important because it can modify the generation and propagation of electromagnetic ion cyclotron waves, which act as an acceleration/loss mechanism for radiation belt electrons.

In the analysis of Forster *et al.*, a pre-onset flux dropout was observed in all the ion data with a recovery beginning immediately after onset. The flux following onset was greater after 20 to 30 hours than the pre-onset flux. The data also indicate that the lower energy ions recover first, changing the heavy ion ratio. Following Borovsky and Denton (2010), who showed that during HSS-driven storms electrons undergo heating at constant number density, Forster *et al.* showed that there was a dropout in the ion number density before the onset time in all four species, with a rapid recovery after onset. As for the flux, the number density after onset recovered to values higher than before the dropout.

Several magnetospheric missions have observed narrow structures in proton data at approximately 1–25 keV in the inner magnetosphere, usually during periods of low geomagnetic activity. These features are often referred to as nose-like or banded structures due to their appearance in time series plots of proton



2: The calculated phase space density of radiation belt electrons at geostationary orbit (R=6.6R_E) as a function of the adiabatic invariants (μ, K, L*), presented by Hartley *et al.* μ and K are fixed, and L* is the inverse of the third invariant. Magnetic field variations reduce L*, indicating outward adiabatic transport of electrons with possible losses to the magnetopause. The reduction in phase space density at L*~5 indicates the contribution of non-adiabatic loss processes.

flux spectra. **Kirthika Mohan** (Mullard Space Science Laboratory) showed Double Star and Cluster data for the electron equivalent of these features, and used a simple forward particle trajectory drift code to model the relevant ion and electron drift orbits at various energies. The authors went on to perform a statistical survey using Double Star TC-1 PEACE (Plasma Electron And Current Experiment) data looking for the location, timing, energy and number of bands in the nose structures in the electron data. Mohan *et al.* found that the electron nose features also occur primarily during quiet times (Kp=0 to 3). Structures with two bands are observed preferentially on the dayside while those with three bands feature more heavily near dusk. Efforts will continue to expand this dataset by looking at TC-2 and Cluster data and investigating the effects of substorms on these nose structures as seen in electron data.

Geomagnetic storms and substorms

Tim Booth (University of Leicester) presented results of an initial analysis of spacecraft wave data during storms, using Cluster as a starting point. The authors used the database of storms from Hutchinson *et al.* (2011) and then reduced the dataset to storms after Cluster launched in July 2000 and those without significant data gaps. They showed plots of ion and electron flux in various energy ranges averaged over the chosen storms along with average B and E-field wave power separated out by wave type and frequency (EMIC, hiss, lightning whistler and chorus). They then compared this to similar plots for quiet times. Future work will show statistically how temporal changes in the wave power affect observations of flux.

Roger Duthie (Mullard Space Science Laboratory) showed work on the distribution of bursty bulk flows (BBFs) during substorms using both Double Star and Cluster spacecraft. A novel hybrid dataset from the Cluster observations of BBFs was created using ExB and particle data, and BBFs were identified using rules based on Raj *et al.* (2002). Double Star TC-1 and TC-2 data were used to look for associated magnetic dipolarizations by eye, following Takada *et al.* (2006), and substorm phases were identified using the AL index from Kyoto and IMF data from the OMNI dataset, following a method from Juusola *et al.* (2011). Duthie *et al.* found that BBFs and dipolarizations were both much more likely to be detected in the expansion and recovery phase, finding more dipolarizations than BBFs. BBFs were found to some extent at all times, including non-substorm intervals for both northward and southward IMF. Dipolarizations were found at all times except southward IMF non-substorm intervals. The data suggest that BBFs measured at Cluster do not typically contribute to substorm current wedge formation and consequent dipolarization.

Saturn's plasma environment

After the poster session, attention turned to Saturn's magnetosphere. The Cassini spacecraft has now taken data on a large number of high-inclination orbits, permitting statistical studies of the cusp, similar to those previously carried out at Earth. Particle precipitation in the cusp can be used to study magnetopause reconnection, which is of particular interest at Saturn as magnetopause reconnection appears to occur less commonly than at Earth. **Jamie Jasinski** (Mullard Space Science Laboratory) presented preliminary results from a statistical study of Saturn's cusps. Eight possible cusp crossings were identified in five months of data. One example cusp crossing was discussed; in the region identified as the cusp, protons were observed but there were no heavier ions – suggestive of plasma of solar wind origin, and hence evidence for magnetopause reconnection at Saturn. The remaining cusp candidates will be subject to further analysis.

Annie Wellbrock (Mullard Space Science Laboratory) presented observations of negatively charged ions observed in Titan's ionosphere by the Cassini CAPS Electron Spectrometer. Although the spectrometer was designed to observe electrons, it also observes characteristic signatures caused by detection of negative ions near Titan, at altitudes below 1400 km (seen as vertical spikes in figure 3). The presence of negative ions was expected at lower altitudes, but not at the altitudes observed by Cassini. The velocities of the negative ions are small compared with the velocity of the spacecraft, hence they are only observed when the instrument points into the apparent direction of flow caused by the spacecraft's motion. This means the speed of the ions relative to the spacecraft is known, and so the mass/charge ratio of the ions can be inferred from the observed energy. The authors presented a statistical study using data from 34 encounters with Titan in which clear negative ion signatures were observed, and found that both the peak density and the maximum altitude at which ions were observed decreased as the ion mass increased. The results of this and subsequent analysis will be useful in constraining the chemical processes which form and destroy negative ions in Titan's ionosphere.

The solar wind and heliosphere

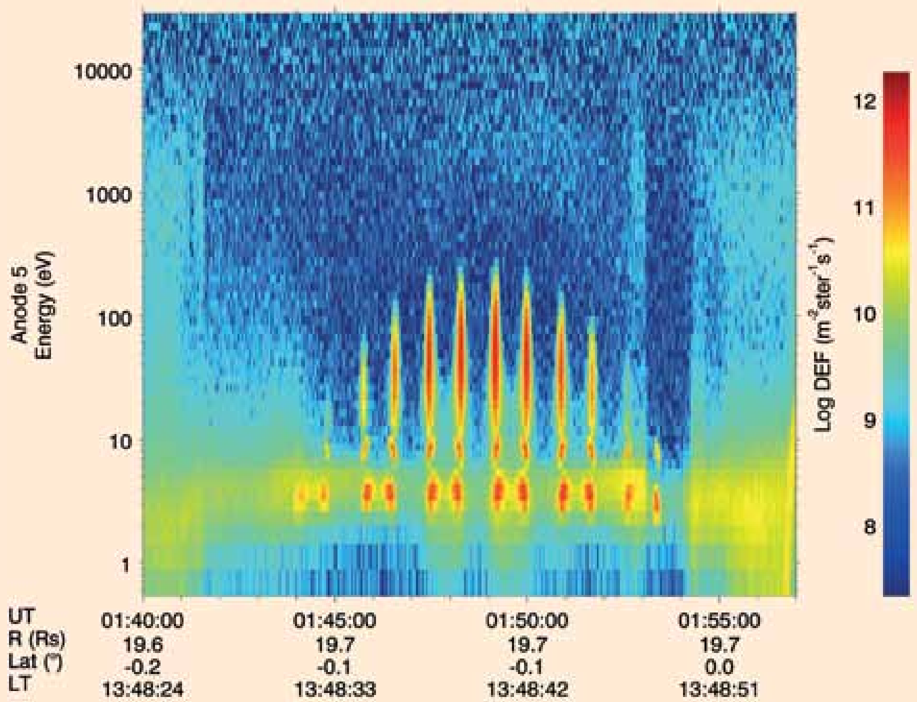
Turbulence is a process which occurs in many laboratory and astrophysical plasmas, and the solar wind provides an excellent accessible natural laboratory in which to study it. Understanding turbulence in the solar wind is a key step in understanding the heating of plasmas; one outstanding problem in this area is the identification of which wave modes are present, and which dominate in the heating process. A previous study (Sahraoui *et al.* 2010) has found kinetic Alfvén waves to be significant in the mediation of solar wind turbulence, but the interval studied occurred during the passage of a coronal mass ejection, which may mean the conditions were not typical. **Owen Roberts**

(Aberystwyth University) presented an analysis of data from four periods of undisturbed fast solar wind. They applied two methods: k-filtering and polarization analysis. k-filtering uses four-point observations (in this case, from the Cluster spacecraft) to calculate the three-dimensional power spectrum. Polarization analysis is used to analyse the turbulent fluctuations in the plane perpendicular to the wave vector found from k-filtering. Both methods produced results that were consistent with kinetic Alfvén waves being dominant at proton gyration scales.

Plasma turbulence is known to be bursty, which is referred to as "intermittency". **Kareem Osman** (University of Warwick) investigated the presence of any link between coherent solar wind structures such as current sheets (identified by a high value of a statistic called the normalized partial variance of increments, or PVI), plasma temperature and temperature anisotropy. High values of PVI were found to occur near the stability thresholds for the mirror and firehose instabilities, which were also associated with enhanced plasma temperatures and temperature anisotropies. This indicates that intermittency is related to the presence of coherent structures in the solar wind, enhanced heating and anisotropy, and to specific plasma instabilities, although the precise mechanism remains unclear (Osman *et al*. 2012).

Andrew Turner (University of Warwick) presented the results of an investigation into the effects of solar wind discontinuities (abrupt changes in the interplanetary magnetic field) on turbulence. The authors developed a means of removing data where the change in the magnetic field from one data point to the next was above a defined scaling relation, without introducing a characteristic timescale to the time series. It was found that removing plasma discontinuities significantly affects the statistical properties of the turbulence power spectrum; the turbulence cascade becomes quasi-isotropic, such that the spectral exponent does not vary with direction. The power law exponent was found to be $-3/2$. Spectral (an)isotropy and the power law exponent are important parameters which are used to distinguish between theories of plasma turbulence. The observed isotropic exponent was consistent with Iroshnikov–Kraichnan turbulence, but not Kolmogorov (which predicts an isotropic exponent of $-5/3$) or Goldreich–Sridhar (anisotropic exponents of $-5/3$ and -2).

The final talk of the day was given by **Simon Thomas** (University of Reading), who discussed a study of the long-term modulation of the flux of galactic cosmic rays (GCRs) by the solar cycle. GCRs originate outside the solar system, and their energies are high enough for them to be detected at the Earth's surface. The flux of GCRs is known to be modulated by the solar cycle, with higher GCR fluxes near solar minimum; GCR flux is further modulated by the polarity of the solar magnetic field and therefore follows a 22-year cycle (the Hale cycle). The peaks in flux are "domed" at solar minima in cycles with outward pointing magnetic flux at the solar north pole ($qA > 0$) and much sharper (spiked) at solar minima in $qA < 0$ cycles. One reason proposed to explain the difference between the "domed" and "spiked" peaks is that it may be due to the path taken by GCRs; when $qA > 0$, GCRs arrive at Earth from the Sun's polar regions, but when $qA < 0$ they arrive along the heliospheric current sheet. The authors presented the results of a superposed epoch analysis for GCR flux through the solar cycle, using observations of secondary GCRs from a neutron detector in Antarctica from the past four solar cycles. The main difference between GCR fluxes in positive and negative qA solar cycles occurred during the declining phase of the cycle, with both of the $qA > 0$ cycles showing markedly higher GCR fluxes as the sunspot number declined than at the equivalent phase of the two $qA < 0$ cycles. Significant differences were also observed between several heliospheric parameters (|B|, open solar flux and the heliospheric current sheet index) in the declining phases of the positive and negative qA cycles, implying that the different GCR peaks in positive and negative cycles may arise from a combination of the differing paths they take (as previously postulated) and variations in heliospheric parameters. But the difference in heliospheric parameters for positive and negative cycles was absent in parameters reconstructed for the previous six solar cycles (before the space age), implying that the variation may only occur during the current grand solar maximum.



3: Negative ions observed by the Cassini CAPS-ELS instrument near Titan, shown by Wellbrock *et al.* Negative ions appear as vertical spikes in the spectrogram, giving a mass/charge spectrum.

This Autumn MIST was, as always, an excellent demonstration of the diverse interests of the MIST community and the high quality of the research in this field. MIST council is grateful to everyone who presented talks and posters at this very well attended meeting. We look forward to more excellent MIST presentations at NAM in St Andrews in July 2013. ●

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Boulby International Subsurface Astrobiology Laboratory

1: The Boulby Mine, located in Saltburn-on-the-Sea in North Yorkshire, is home to the Boulby International Subsurface Astrobiology Laboratory (BISAL).

Charles S Cockell, Samuel Payler, Sean Paling and Dave McLuckie outline plans for the first underground astrobiology facility.

Boulby Mine, in Cleveland, northeast England, is the UK's only working potash mine and is one of the deepest mines in Europe at 1.1 km (figure 1). Already the home of the Boulby Underground Laboratory (Murphy and Paling 2012), hosting dark-matter research and various other deep underground and "low-background" radiation science studies, the mine is preparing to expand its scientific programme with the establishment of BISAL (Boulby International Subsurface Astrobiology Lab), the world's first subsurface astrobiology laboratory (figure 2). Research at the laboratory will have two main focuses: *in-situ* deep subsurface astrobiology, and space technology development (including extraterrestrial analogue research). BISAL has been established as a facility by the UK Centre for Astrobiology in collaboration with the STFC-supported Boulby Underground Laboratory and Cleveland Potash (CPL), who run the mine. The laboratory is being equipped with support from the STFC Futures Programme.

Deep biology and Mars analogues

Interest in the study of environments with analogues to Mars, past and present, has been consolidated in recent times by a combination of high-profile exploration missions and a growing body of evidence indicating that Mars once had a warmer, wetter climate than today (Carr and Head 2010). Boulby's geological environment provides a compelling example of such an analogue (figure 3). The mine exploits the Zechstein formation, an evaporite sequence deposited in the waters of the Zechstein Sea, which covered part of northwest Europe during the mid-to-late Permian, approximately 260 to 250 million years ago. Exposed in the mine's vast tunnel network are sequences of chloride and sulphate minerals such as sylvite, halite, anhydrite, gypsum and polyhalite.

BISAL

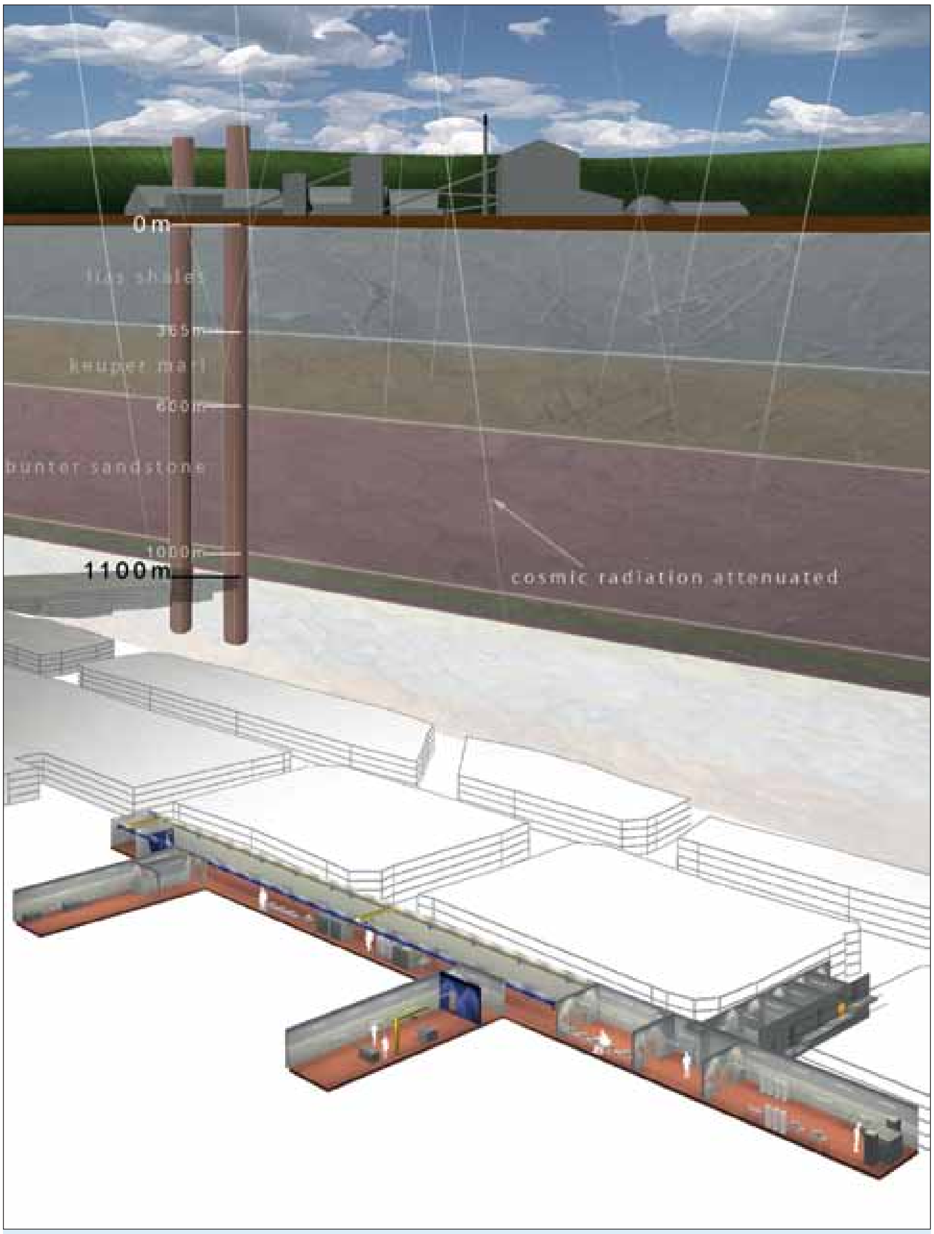
Boulby International Subsurface Astrobiology Lab

Over recent years, similar minerals have been detected on the martian surface. Primarily, these appear to consist of thick sulphate layers composed of minerals such as gypsum and jarosite deposited in the acidic aqueous conditions of the mid-to-late Noachian to early Hesperian, approximately 3–3.5 billion years ago (Squyres *et al.* 2004, Langevin *et al.* 2005). However, chloride minerals have also been detected in martian meteorites (Bridges and Grady 1999) and tentatively from orbit (Osterloo *et al.* 2008). While martian fluid compositions would have been distinctly different from those associated with the Zechstein sequence (more acidic and enriched in Fe, Ca, Mg and SiO_2), a great diversity of salt minerals are still predicted to have formed at particular stages of martian fluid evolution (Tosca and McLennan 2006), including, to varying extents, all the minerals found in Boulby. Although direct observation is yet to confirm such a variety of minerals, there is a strong case to suggest that, at least on local scales, mineral assemblages analogous to Boulby exist within the martian subsurface.

Subsurface evaporites could play an important role in preserving and/or recording the existence of martian biology, if it ever existed. Indeed, microbes have long been known to exist in evaporite deposits (Dombrowski *et al.* 1963) and were of astrobiological interest even before their detection on Mars (e.g. Rothschild 1990). In Boulby, and other salt mines around the world, brine flows encountered during mining operations contain various halophilic organisms. Norton *et al.* (1993), for example, isolated several different halobacteria (haloarchaea) from Boulby, including organisms from the genera *Haloarcula* and *Halobacterium*. Fluid inclusions contained within salt crystals have even been shown to entomb viable halophiles

Workshop
From Outer Space to Mining: Technology Transfer from Extraterrestrial Extreme Environments to the Earth

This workshop will be held on 24 April 2013 at Boulby Mine, with the goal of bringing together developers and potential users to investigate how astrobiology/space technologies and instruments can be used to enhance mineral extraction and mining safety. There will be presentations on aspects of instrumentation for space or extreme environments that could be applied to the mining environment. This workshop is part of a commitment of UKCA to assist the transfer of technologies from astrobiology and space exploration to solving Earth-based problems.
http://bit.ly/XMSTIk



2: BISAL uses part of the existing Boulby Underground Science Facility (the Palmer laboratory).

(Norton *et al.* 1993, Vreeland 2000, Schubert 2010). While these subterranean environments appear dominated by archaea, the isolation of the red-pigmented bacteria *Salinibacter ruber* from Spanish salterns (Antón *et al.* 2002) indicated that certain bacteria employing similar mechanisms of haloadaptation to haloarchaea (Oren *et al.* 2002) could make up a more significant ecological component of hypersaline environments than previously thought.

The extent to which these halophilic communities interact with the surface environment on geological timescales is unclear. Consequently, much debate surrounds their origins. Hypotheses range from the invasion of modern halophiles to descendants from the original population inhabiting the Zechstein Sea, to even genuine Permian organisms locked in crystalline brine inclusions and awakened from stasis by dissolution (e.g. Vreeland *et al.* 2000, McGenity *et al.* 2000, Graur and Pupko 2001). Regardless of their exact origins, the ubiquity of halophilic organisms across terrestrial salt deposits highlights life's ability to access and survive in deep subsurface evaporites for considerable periods of time.

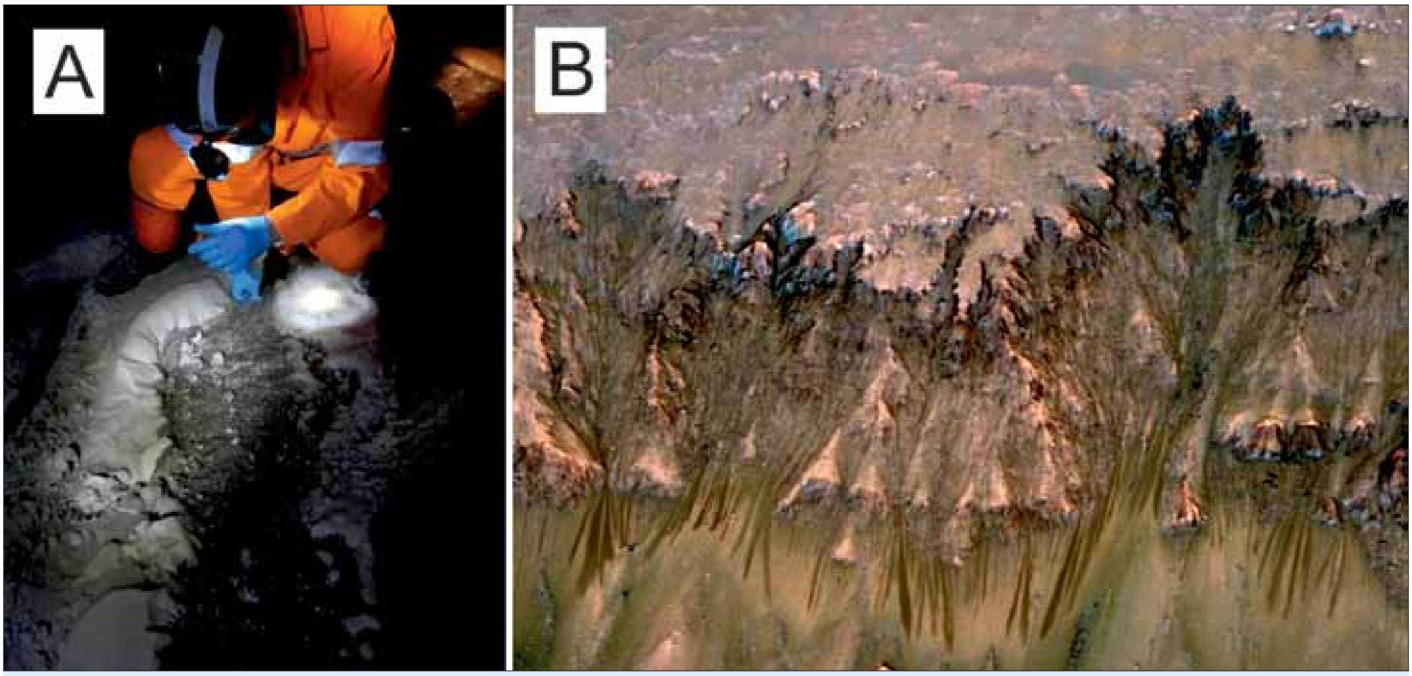
Martian subsurface

Subsurface evaporite deposits provide knowledge that can be applied to assessing the habitability of the martian deep subsurface. The past 40 years of martian exploration has shown that early Mars experienced episodically warmer, water-rich periods potentially more conducive to supporting life than the modern planet. Although the surface of Mars is now uninhabitable because of the high levels of ionizing radiation, extreme temperature fluctuations and desiccation, the sheltered subsurface could provide a more habitable environment.

In addition to the preservation of viable microbial communities, evaporite deposits are also capable of recording other biosignatures. A number of studies have demonstrated that the organic matter co-deposited with evaporites can be preserved for remarkably long periods of time given a favourable local radiation regime. For example, sulphate minerals including gypsum, anhydrite and jarosite from a number of different evaporite sequences were found to contain organic material displaying chemical signatures indicative of an ancient origin (Aubrey *et al.* 2006). Similarly, Permian halite of the Salado Formation in southeastern New Mexico, examined by Griffith *et al.* (2008), was found to contain an abundance of cellulose microfibres believed to be derived from Permian algae and plant debris. The preservation of viable microbial communities in the deep subsurface evaporites, combined with their temporal and spatial association with liquid water and organic material, make extraterrestrial evaporite deposits exceptional astrobiological targets and analogues for assessing approaches to life detection.

Earth science

Quite apart from Mars analogue studies, BISAL will provide other capabilities for the study of Earth's biosphere. Little is known about the role of microorganisms in deep subsurface processes, including the iron, sulphur and carbon cycles and the biogeography of life in the deep subsurface (Reith 2011). By establishing a permanent deep subsurface microbiology facility, BISAL provides a focal point to advance our understanding of deep subsurface microbiology and its role in global biogeochemical processes. These data have the potential to improve knowledge about the limits of life in extreme environ-



3: Deep subsurface habitats in Boulby include brine seeps and streams (A), that in addition to providing insights into life in the terrestrial deep subsurface, provide geochemical and astrobiological analogous environments for assessing putative brine seeps observed in locations such as the rim of the 300 km diameter Newton Crater, Mars (B; image: NASA).

ments and particularly organisms in salt-rich habitats (figure 3).

Understanding the geochemistry and geobiology of deep subsurface environments is of general interest for improving our knowledge of challenges in establishing deep geological repositories for carbon capture and storage. Thus, although Boulby itself is not proposed as a geological repository, the study of deep subsurface sites in general not only contributes to fundamental science, but has direct applicability to environmental science priorities in geological repositories, energy and climate change.

BISAL and technology development

As well as its science focus, BISAL will become the focus of a technological mission with a particular emphasis on space technology. One of the mission objectives of the UK Centre for Astrobiology is to advance the translation of space technology used to study extreme extraterrestrial environments to the solving of terrestrial problems.

There are two aspects of Boulby that make it attractive as a location for testing space technology. First, the isolated environment and challenging physical and chemical conditions combined with the on-site clean laboratory facilities make it an ideal proving ground for analysing the performance of miniaturized, rugged instruments to be used in robotic and human planetary exploration. For example, miniature instruments to be used for characterizing the geochemical and geological features of extraterrestrial environments can be tested, as can life-detection technologies designed to identify organics and gases. This can be done within the context of the science investigations described above.

There are many potential technological synergies between the space exploration and mining safety/mineral exploitation communities. Both require small instruments that will withstand extreme conditions and can be deployed in confined spaces with low detection limits. For example, space instrument developers may aim to build instrumentation able to detect low concentrations of gases in planetary atmospheres, while miners could make use of that technology to improve the monitoring of hazardous gases (for example, methane). BISAL will be used as a platform for testing such technological synergies. A workshop to be held in 2013, From Outer Space to Mining, will bring together the space exploration and mining communities to develop this synergy.

Secondly, Boulby can be used to test technologies for the robotic and human exploration of other planetary bodies in general. Subsurface environments such as lunar and martian lava tubes and deeper subsurface sites are challenging to access. Robots, placed into Boulby, can be operated from BISAL or its surface element, to test technology, mission operations, communications protocols, science protocols and other elements of an extraterrestrial mission architecture. In 2013, the UK Centre for Astrobiology will host a two-day workshop with participants from Surrey Space Centre, NASA and DLR to discuss and plan an analogue programme based around BISAL. NASA participation is being funded by the NASA Astrobiology Institute. Over the two days a comprehensive analogue strategy will be developed for the coming years, with plans to continue to host the From Outer Space to Mining workshop as an annual feature of the analogue mission.

Over the years ahead, we hope that BISAL will become a useful and versatile facility that will act as a focus to advance UK science and technology, improve our capacity to contribute to international activity in astrobiology, and act as the UK's first Mars and extraterrestrial analogue facility. In the process we can act as a catalyst in bringing the space exploration community together with those interested in solving urgent terrestrial challenges. ●

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Big Bang: the etymology of a name

Fred Hoyle famously coined the term "big bang" in 1949, but it took a long time to catch on. Helge Kragh shows how the story of the name is also the story of how modern cosmology emerged.

A Google search for the combination "big bang" and "universe" gives 28.6 million returns, a rough indication of the popularity of the term that since the late 1960s has been almost synonymous with the standard model of modern cosmology. Ironically, the term was coined by Fred Hoyle (figure 1) in 1949 to characterize the kind of theory he much disliked and fought until the end of his life. Although it is widely agreed that Big Bang is a misnomer because it inevitably conveys the image of an explosion, the term has long ago become a staple part of cosmologists' vocabulary. More than a thousand scientific articles have been written with "big bang" in their title. As Hoyle said in an interview in 1995: "Words are like harpoons. Once they go in, they are very hard to pull out" (Horgan 1995).

It is worth looking at the etymology of scientific names and phrases that catch on, because they influence how scientists and the public at large think about Nature. "Relativity theory" – a name for which Einstein was not responsible – may allude to relativism ("everything is relative") in the same way that "big bang" alludes metaphorically to an explosive and noisy event at the beginning of time. Both convey unfortunate pictures, but it is difficult to find substitutes that are both apt and more appropriate.

A detailed study of the history of the name Big Bang reveals misunderstandings in the popular and scholarly histories of modern cosmology. For example, the epic cosmological debate in the period 1948–1965 is usually described as a fight between two rival world systems, the Big Bang theory and the Steady State alternative. This is to a large extent a misrepresentation in both a terminological and factual sense. It is "well known" that Hoyle coined the term "big bang" in a pejorative sense, to make fun of the idea of an exploding universe, but what is well known is not necessarily correct. It is also generally assumed that the name was adopted by the cosmologists at an early stage and widely used in the controversy. This was not the case. It took more than two decades until Hoyle's phrase became common in the scientific literature.

Early explosion theories

The Belgian physicist and cosmologist Georges Lemaître is often mentioned as the father of the physical big bang, a concept he introduced in 1931. Incidentally, the origin of his finite-age model is often misdated to 1927, the year in which he developed a pioneering theory of the expanding (but non-big bang) universe. Even the authoritative *Oxford English Dictionary* states Lemaître's Big Bang theory to date from 1927. To describe in words the initial state of the universe he had recourse to metaphorical terminology, his favourite names being "primeval atom" and "fireworks theory". One name he did *not* use was the "cosmic egg", to which there are

1 (left): Fred Hoyle (1915–2001).
2 (right): George Gamow (1904–1968).

nevertheless several references in the literature, none of them with a source reference. With the benefit of hindsight we can today recognize in Lemaître's primeval atom hypothesis the germ of the later Big Bang theory, but in the 1930s it was scarcely taken seriously. Most astronomers either ignored it or dismissed it as "clever *jeu d'esprit*", as one critic called it.

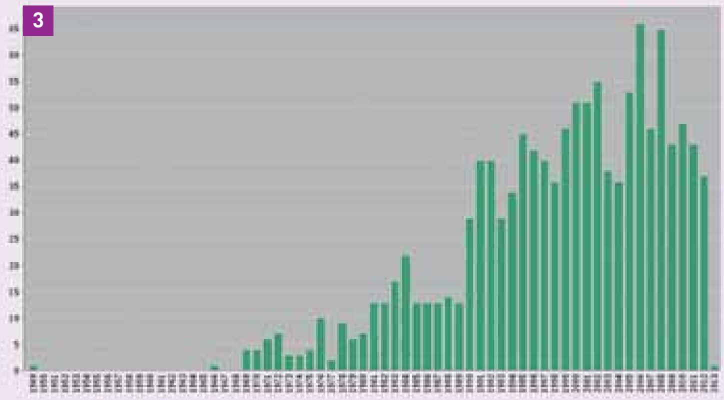
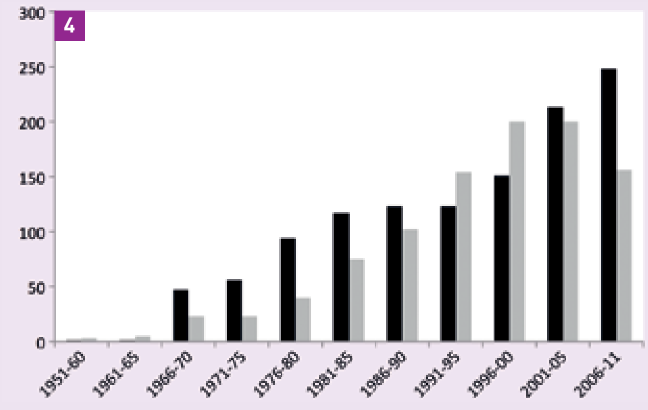
It was only in the late 1940s that George Gamow (figure 2) and his collaborators Ralph Alpher and Robert Herman independently transformed Lemaître's spirited hypothesis into a sophisticated model of the early universe. They assumed the initial state to consist of a very hot, compressed mixture of nucleons and photons, thereby introducing the hot Big Bang model. On this basis they succeeded in calculating the amount of helium in the universe (about 30%), but unfortunately there were no reliable observations with which their calculations could be compared. Although Gamow did not associate the early exploding universe with a particular name or phrase, he did coin a name for the collapsing universe he imagined might have preceded the present expansion (Gamow 1951). He sometimes referred to the "big squeeze" in terms that were almost indistinguishable from the Big Bang, a name he resented. As he said in an interview shortly before his death in 1968, it was a cliché (Gamow 1968).

Hoyle coins a phrase

As one of the founders of the Steady State theory of the universe, together with Hermann Bondi and Thomas Gold, Hoyle was strongly opposed to cosmologies with a beginning in time. On 28 March 1949 he gave a talk on his favoured "continual creation" theory to BBC's Third Programme which shortly thereafter was reproduced in *The Listener*, the widely circulated BBC magazine. He emphasized the contrast between the Steady State theory and "the hypothesis that all matter of the universe was created in one big bang at a particular time in the remote past", which he found to be "irrational" and outside science. Less than a year later he gave a series of five broadcasts on the BBC which again were printed in *The Listener* and also in the form of the best-selling book *The Nature of the Universe*. With Hoyle's radio lectures of 1949–1950 the term "big bang" made its entry in the cosmological vocabulary.

There are in the literature some misconceptions about Hoyle's BBC addresses and the effect of his neologism. One of them is that Gamow was directly involved in Hoyle's BBC talks, such as stated by Alpher and Herman in several of their recollections: "Toward the end of 1949 Gamow engaged in a transatlantic debate with Hoyle on the BBC. It was during this debate that Hoyle first used the designation 'Big Bang', and in a pejorative sense" (Alpher and Herman 1997). There never was such a radio debate between the two cosmologists, and Hoyle did not mention Gamow in his talks or in his book. Nor is it true, as one can read in some sources, that Gamow promoted the term Big Bang or – even worse – that he invented it. In fact, the cosmological controversy was not really between the Steady State theory and the Big Bang theory in either Lemaître's or Gamow's sense, and it was even less a fight between Hoyle and Gamow.

In the American popular press the controversy over the universe was usually put in the context of Hoyle versus Gamow, which is a misrepresentation if perhaps an understandable one from a journalistic point of view. Gamow's theory of the early universe played very little role in the predominantly British debate and Hoyle rarely referred to it. Characteristically, when the BBC arranged a radio symposium on modern cosmology in 1959, focusing on the controversy between the Steady State theory and the relativistic evolution theories, no speakers referred to Gamow's Big Bang theory or Lemaître's prime-

3: Web of Knowledge data showing the number of science papers with "big bang" in their title (as of December 2012). Total number 1205.
4: Number of articles or notes 1951–2011 in *Nature* (black) and *Science* (grey) with references to big bang. Not all the references are to cosmology, but the vast majority are.

val atom hypothesis (Bondi *et al.* 1959).

Was Hoyle's use of "big bang" intended to be pejorative, as stated by Alpher and Herman and numerous other authors? This is possible, of course, but the evidence for the claim is unconvincing. In the British edition of *The Nature of the Universe* Hoyle twice referred to "big bang", and in neither of the cases in ways that were clearly derisive. Neither Gamow, Lemaître nor other protagonists of explosion cosmologies felt at the time offended by the term or paid any attention to it. Moreover, in the many reviews of the book and critical comments on the BBC broadcasts, the name for the exploding universe that Hoyle had so casually invented played no role. As a broadcaster Hoyle needed word pictures to get over technical and conceptual points, and "big bang" was just one of them.

As to Hoyle himself, he considered the name an apt but innocent phrase for a theory he was opposed to. In an interview of 1989, he insisted that he had not thought of it in a derogatory sense. "I was constantly striving over the radio – where I had no visual aids, nothing except the spoken word – for visual images," he said. "And that seemed to be one way of distinguishing between the steady-state and the explosive big bang. And so that was the language I used," (Lightman and Brawer 1990). The non-pejorative interpretation is further strengthened by the uses of "big bang" in the cosmological debate. If Hoyle had coined the name to ridicule or disparage theories with a definite origin of the universe, he would presumably have used it frequently during the heated controversy, which he did not. After 1950, he only returned to it in 1965 (Hoyle 1965). In the same period his steady-state allies Bondi and Gold also refrained from referring to the term. Finally, the supposedly derogatory part of the name Big Bang must be "bang", a term that Eddington had used for finite-age cosmological models as early as 1928. "As a scientist I simply do not believe that the universe began with a bang," he said, inventing half of the later term (Eddington 1928). No-one felt Eddington's designation to be pejorative.

Catchy but unpopular

Hoyle's term came to be seen as compelling and catchy, and sometimes controversial, but originally this was far from the case. It simply did not catch on in either of the cosmological camps and appeared only insignificantly in the scientific literature until the 1970s. Although no scientific paper in the early period included "big bang" in its title, the term appeared a few times in both the scientific and popular literature, and especially in American popular magazines such as *Science News Letter* and *Popular Science*. I have located 34 sources that mention the cosmological big bang before 1965. Of these, 23 are of a popular or general nature, 7 are scientific contributions and 4 are cited in the philosophical literature. The authors include 16 Americans, 7 Britons, 1 Australian and 1 German.

With the exception of one paper, all of the early references to "big bang" were brief and uncommitted. The exception was an essay of 1961 in which the eminent British–American astronomer George McVittie reviewed the Steady State theory and the Big Bang theory in equally critical terms. As he pointed out, the idea of a physical big bang was not legitimated by the solutions to the Friedmann equations corresponding to $R=0$ for $t=0$. "General relativity predicts no nuclear explosion, big bang, or instantaneous creation, for that matter, as the cause of the start of the expansion at that moment," he said, adding that such notions were due to "imaginative writers" (McVittie 1961). He probably thought of Gamow and Lemaître. In a later paper (McVittie 1974), written after the hot Big Bang had become the standard model of cosmology, McVittie deplored the popularity of the term "big bang", which he found inappropriate because of its association to an exploding cosmic bomb.

Only three scientists referred to "big bang" in research publications before 1965, and none of them used the term pejoratively. Otto Heckmann, a distinguished German astronomer and cosmologist, agreed in a paper of 1961 with McVittie's point that a big bang does not follow from either the Hubble law or the Friedmann equations. The American nuclear physicist William Fowler, a later Nobel Prize winner, worked closely with Hoyle on the celebrated theory of stellar nucleosynthesis known as the B^2HF theory (the two other contributors were Margaret and Geoffrey Burbidge). Although "big bang" did not appear in the B^2HF paper, Fowler used it in another publication of 1957. He may have been familiar with the name from his discussions with Hoyle. Also, 28-year-old Steven Weinberg, who introduced "big bang" in the pages of *Physical Review* while examining the role of neutrinos in cosmological models (Weinberg 1962), was in contact with Hoyle.

Astronomers and physicists were not the only ones to make sporadic use of the name Big Bang before 1965. Norwood Russell Hanson, a philosopher of science at Yale University, apparently liked the term which he used repeatedly in an analysis of the concept of creation in the two competing world systems. Moreover, he coined his own word for supporters of what he called the "Disneyoid picture" of the exploding early universe, namely "big bangers". According to Hanson (1963), the difference between the big bangers and the continual creators was basically semantic, rooted in different meanings given to words such as creation and universe. However, he seriously misunderstood the Steady State theory, stating that it shared with the Big Bang theory the view that in the far past the universe was quite different from what it is now.

Revival of the Big Bang

On 21 May 1965 the *New York Times* included on its front page an article entitled "Signals Imply a 'Big Bang' Universe". The occasion was the sensational discovery of a cosmic microwave background that changed the course of cosmology and effectively eliminated the already ailing

Steady State theory. In a now classic paper of July 1965, written by Robert Dicke, Jim Peebles, Peter Roll and David Wilkinson, the discovery was interpreted as the fossil radiation from the early universe. The authors referred to the "primordial fireball", a name suggested by John Wheeler, but not to the Big Bang. Only in 1966 did Peebles use the name, apparently identifying it with the phase of element formation in Gamow's theory. The same year we meet the first research paper referring to "big bang" in its title, an investigation of Stephen Hawking and Roger Tayler concerning the synthesis of helium in anisotropic models of the early universe. Contrary to Peebles, they spoke of the Big Bang as the initial space–time singularity.

In the late 1960s the Big Bang bandwagon was rolling, although the name "big bang" lacked somewhat behind the bandwagon. The *Web of Knowledge* lists only 11 scientific papers in the period 1960–1970 with the name in their titles, followed by 23 papers in the period 1971–1975. On the other hand, Hoyle's name appeared with increasing frequency in newspapers and the popular literature, in almost all cases employing the explosion metaphor that scientists find so misleading. In any case, a decade after the discovery of the cosmic background radiation the hot Big Bang theory had acquired a nearly paradigmatic status. While a poll among predominantly American astronomers in 1959 showed 33% to be in favour of the Big Bang picture, in a later poll of 1980 the figure had increased to 69% (Brush 1993). It would have been considerably higher had the poll been restricted to astronomers active in cosmological research.

The new paradigm was followed by new textbooks. In 1971 Peebles published *Physical Cosmology* and Dennis Sciama the more elementary *Modern Cosmology*, both of them solidly anchored in the now paradigmatic hot Big Bang theory and making use of the term "big bang". Not all textbook authors felt the term attractive or appropriate. Although Weinberg had used it as early as 1962, in his advanced text *Gravitation and Cosmology* of 1972 it only appeared once. He preferred to speak of the "standard model". Yet another important book from the early period, Yakov Zel'dovich and Igor Novikov's encyclopedic *Relativistic Astrophysics*, avoided the term altogether. The two Russian authors based their exposition on what they called the Friedmann theory of a singular beginning of the universe, referring throughout to the "theory of the hot universe" as an alternative to the hot Big Bang theory.

A Big Bang poem

The two Cambridge astronomers Fred Hoyle and Martin Ryle disagreed violently about the measurements of "radio stars" and their cosmological significance. The disagreement evolved into a major feud, which in the early 1960s inspired Barbara Gamow, the wife of George Gamow, to write a poem on an imagined discussion between Ryle and Hoyle (Gamow 1968). In two of the verses Hoyle speaks to Ryle:

Said Hoyle, "You quote
Lemaître, I note,
And Gamow. Well, forget them!
That errant gang
And their Big Bang –
Why aid them and abet them?
You see, my friend,
It has no end
And there was no beginning
And Bondi, Gold,
And I will hold
Until our hair is thinning!"

Big bang outside cosmology

Astronomers and physicists naturally associate the term "big bang" with the origin of the universe. It may come as a surprise to learn that the first scientific paper with "big bang" in its title was received by the *Journal of Meteorology* two months before Hoyle coined his memorable phrase (Cox *et al.* 1949). The subject of the paper was the meteorological effects of a large TNT explosion. Indeed, in so far that "bang" often refers to an explosion of some kind – and not necessarily a cosmic one – one should not be too surprised to read of big bangs in non-cosmological contexts. Such usage was fairly common during the Cold War period in the 1950s and 1960s, when "big bang" typically referred to nuclear weapons. What *The Economist* called the big bang in a note of 2 February 1957 was a reference to the British plan of testing a hydrogen bomb. The same connotation appears in John Osborne's play *Look Back in Anger*, which was first performed in 1956. Jimmy Porter, a young disaffected man of working-class origin, says: "If the big bang does come, and we all get killed off, it won't be in aid of the old-fashioned, grand design. It will just be … as pointless and inglorious as stepping in front of a bus."

With the paradigmatic status of hot Big Bang cosmology in the last quarter of the 20th century, Hoyle's old name finally caught on. And yet the number of scientific papers referring to "big bang" remained low until about 1990, after which it increased drastically. The *Scopus* database includes 4077 papers from 1960–2012 with "big bang" in title, abstract or key words, of which 3673 are in the physical sciences. The corresponding figures for 1960–1989 are 422 and 404, respectively. Another way of illustrating the popularity of the "big bang" term is to search for it in the databases of journals such as *Nature* and *Science*. As a result of the popularity of the name in cosmology, and of cosmology's wide appeal, since the 1980s the term began to appear in many other contexts as well.

About 10% of all academic articles relating to "big bang" appear in articles outside the astronomical and physical sciences, in particular in biological and economic studies. Thus, the Tunguska event in 1908 has been described as "Siberia's big bang", and biologists sometimes speak of the sudden appearance of life forms in the Cambrian era almost 600 million years ago as "biology's big bang". Likewise, the big bang metaphor has been used extensively in discussions of how to transform centrally planned economies into market-oriented ones, as in the cases of China and Eastern Europe. Today the big bang label is also used in a variety of commercial, cultural and artistic contexts that has only the name in common with the cosmological meaning of the term. Numerous music albums, television series, films, comics, sport events and commercial products of all sorts carry the name that Hoyle casually coined in 1949.

Many people feel that "big bang" is an unfortunate name, not only because of its association with a primordial explosion, but also because it is such an undignified label for the most momentous event ever in the history of the universe. When *Sky and Telescope* ran a competition in 1993 to find a more suitable name, the judges received no less than 13 099 responses. None of them were found worthy of supplanting Hoyle's "inappropriately bellicose" name (Beatty and Fienberg 1994). It had stuck – like a harpoon. ●

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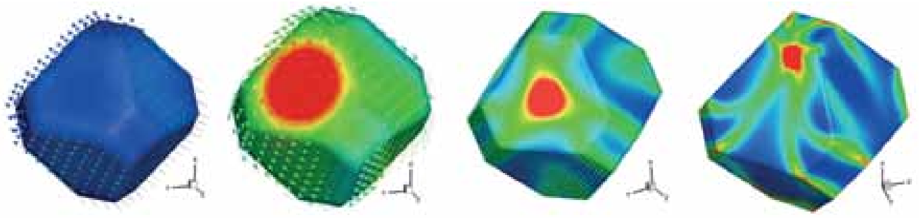
The role of magnetic interactions in natural systems

Inter-particle magnetic interactions between crystals in natural systems strongly affect their magnetic response. In the Bullerwell Lecture 2011, Adrian Muxworthy discusses how these interactions affect our ability to recover from rocks information about the ancient geomagnetic field behaviour, plate tectonics and palaeogeography, and how magnetotactic bacteria utilize interactions to improve navigational efficiency.



1: Magnetic domain structures in cubo-octahedral grains of magnetites obtained using micromagnetic modelling. The magnetization is coloured according to vorticity that highlights non-uniform structures. Grains smaller than 80nm are in the single domain (SD) state. Above 80nm a vortex state is nucleated. This vortex state persists for a large range of grain volumes with more complex states starting to emerge above 1000nm. When SD particles are smaller than a critical (blocking) volume (~30nm for magnetite at room-temperature) they are no longer magnetically stable because thermal energy can easily overcome the energy barrier that prevents domain switching. Such particles have superparamagnetic behaviour; they retain no magnetic remanence. All these domain-states are common in Nature though only non-interacting stable SD grains carry a reliable magnetic remanence; magnetically interacting SD grains also do not reliably record the field.

In the material science world it is possible to construct systems with limited or well-understood magnetic interactions, in striking contrast to Nature where we find complex magnetic systems that are far from ideal magnetic recorders. However, the contribution and understanding of these magnetic interactions have largely been ignored by the mineral-magnetic and palaeomagnetic community because the problem is highly nonlinear; in many natural systems it is argued that the role of magnetic interactions is limited. Nonetheless, in recent years, with the development of new instruments and synthesis techniques by the material science community and the great advances in computational hardware, it is now possible to try to understand these systems.

In this article I give an overview of the types of different interactions found in natural systems, and how we study them. I present data from a number of studies and finally will discuss how magnetic interactions found in living organisms can enhance navigational capability.

Magnetic domain states

Magnetic interactions between particles depend on the magnetic states of the particles. The smallest magnetic grains have near-uniform magnetization as all their atomic magnetic moments are aligned parallel to each other: such structures are termed single domain (SD) (see figure 1a). In larger grains the magnetic structure breaks up into discrete regions separated by magnetic domain walls, and are termed multidomain (MD) (figure 1d). Small MD grains, above the SD/MD threshold size (~100nm for magnetite) display SD-like characteristics though they have non-uniform magnetizations, and are often referred to as pseudo-single domain (PSD). Small PSD grains commonly have "vortex" structures, consisting of a curling outer region with a central core (figures 1b and 1c).

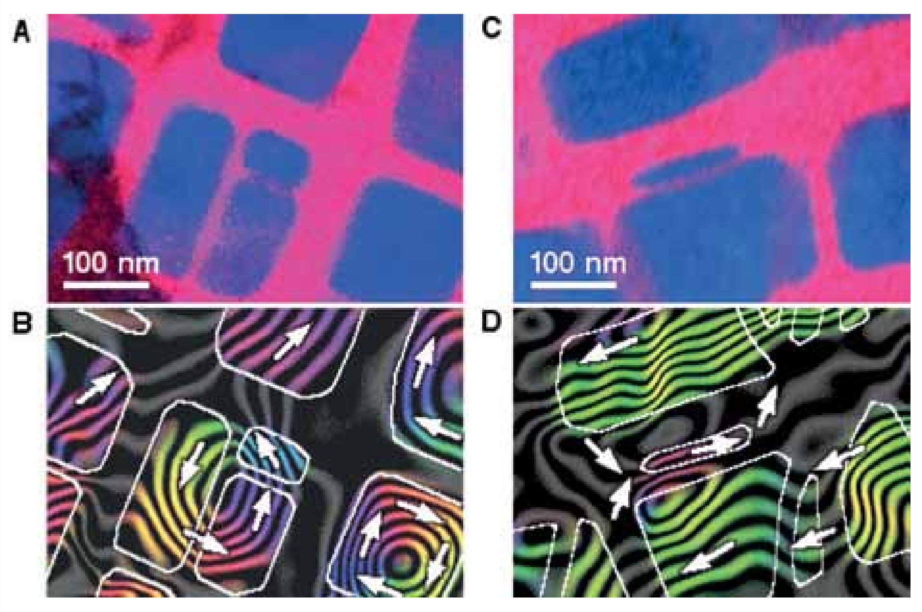
Dynamic and static interactions

In systems of interacting grains, both superparamagnetic (SP) grains, that do not retain magnetic remanence and stable domain states (i.e. SD, PSD and MD grains), contribute to the interaction field. The magnetic interaction field generated by a stable grain is constant during the rotation or structural change of a neighbouring grain's internal magnetic structure. This makes it possible to treat magnetic interaction fields arising from stable domain states grains as effectively static (Spinu and Stancu 1998), and for modelling purposes we can treat the interaction field like a variable "external" magnetic field (Dunlop and West 1969).

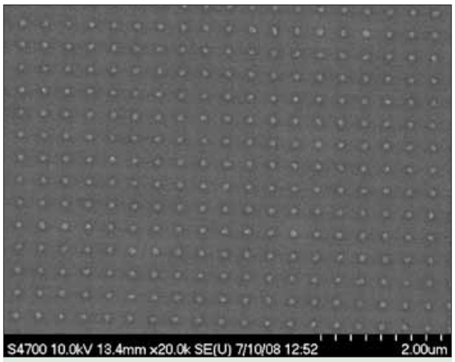
For interacting SP grains, the situation is more complicated. The behaviour of an assembly of SP particles falls into one of three regimes depending on the inter-particle interactions (Dormann *et al.* 1997): (i) a pure SP case (non-interacting), (ii) an SP state modified by interactions, and (iii) a glass collective state. The properties of state (iii) are close to those of spin glasses with a phase transition. This state is not fully understood and there is no simple model for the collective state. There are models for state (ii); these dynamic interactions are qualitatively different from static ones, as dynamic systems are not in thermodynamic equilibrium and hence cannot be directly modelled using Boltzmann statistics. Several approaches have been developed to address this problem (Dormann *et al.* 1988); these models demonstrate that the effect of interactions due to SP grains is to increase their relaxation time due to thermal fluctuations.

Understanding the effect of interactions

To try to quantify the contribution of interactions to natural magnetic systems, both experimental and numerical approaches have



2: Two areas of a finely exsolved titanomagnetite sample from Mount Yamaska, Quebec. In A and C the blue regions show magnetite blocks which are separated from each other by paramagnetic ulvöspinel. B and D show the corresponding magnetic phase contours measured using electron-holography from the same regions. In B, three adjacent magnetite-rich regions combine to form a "super vortex"; and D shows a small region that is magnetically antiparallel to its larger neighbours. (From Harrison *et al.* 2002)



3: Scanning electron microscope image of EBL-produced thin-film sample DK0124 which has a dot diameter of 74 nm and separation of 300 nm. Each thin-film contains millions of near-identical magnetite dots. (From Krása *et al.* 2011)

been taken. The principal areas are direct observations of static magnetic interactions in rocks, synthesis of ideal samples combined with electron-beam lithography, and numerical modelling.

Recent improvements in advanced transmission electron microscopy (TEM) techniques, in particular the method of off-axis electron holography, allow direct imaging of the magnetic fields within and between crystals on nanometric scales (Dunin-Borkowski *et al.* 1998). Because the image is constructed from the shift in phase that occurs when the electron beam passes through a magnetic field, the technique also images the static magnetic fields between magnetic crystals. The resolution of the TEM and the ability to image inter-grain magnetic fields makes this a significant improvement on previous methods such as Bitter pattern imaging, magneto-optical Kerr (MOKE) microscopy and magnetic force microscopy (MFM), when studying inter-grain magnetic interaction fields, though the other methods all have their benefits.

In a pioneering study, Harrison *et al.* (2002) examined the magnetic structure in a finely exsolved titanomagnetite from Mount Yamaska, Quebec, one of the Monterigian Hills of Cretaceous age. The sample consisted of areas of magnetite blocks separated from each other by paramagnetic ulvöspinel (figure 2a). The magnetic structures in individual grains displayed inter-grain coherent magnetic structures, the so-called "super-vortex" states, similar to the vortex state seen in the PSD (figure 1b). By examining samples of a similar size, it is clear that the interaction fields are sufficient to enable grains above the single-domain/vortex transition size, to be in a SD-like state.

Subsequent studies have examined magnetic structures in synthetic rocks and meteoritic samples (Church 2011, Lappe *et al.* 2011), and have examined magnetic interactions across phase boundaries. One of the main benefits of this technique is the direct crossover with micromagnetic models (see below).

Experimentally quantifying the role of interactions in bulk samples is particularly difficult in small crystals of commonly occurring magnetic minerals like magnetite, because it is necessary to control accurately the size and shape of the crystals, plus the inter-grain spacing. Conventionally, samples with small crystals are grown through various aqueous and hydrothermal techniques, which produce stoichiometrically (in terms of chemical purity) perfect crystals with normal or log-normal grain distributions and uncontrolled inter-grain spacings. As small magnetic crystals behave like "mini-bar-magnets", the mobile crystals tend to clump together to form clusters. Such clusters are not representative of the magnetic minerals found in rocks, which tend to grow within the matrix and are not free to cluster.

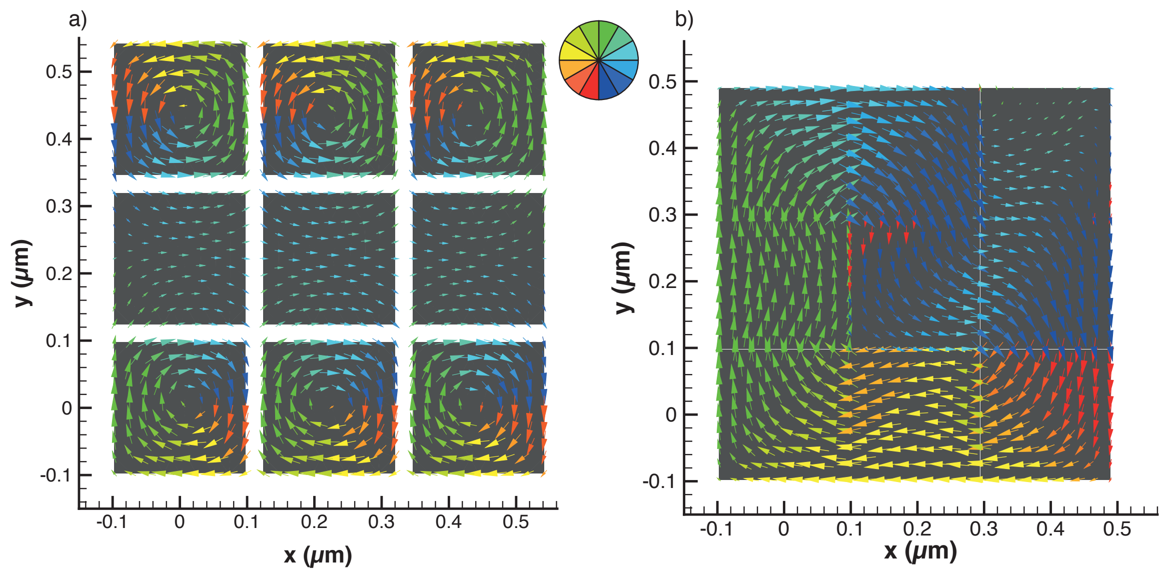
Several techniques have been developed for synthesizing crystals that are fixed and not free to rotate. For example, the glass-ceramic method (Worm and Markert 1987) produces fixed crystals in silica matrix, i.e. they are essentially synthetic rocks; however, there are still problems with this technique. It is difficult to obtain narrow grain size distributions, and it can also be difficult to maintain even stoichiometry across this grain-size distribution, plus such samples are thought to contain very high levels of internal dislocations, higher than is found naturally in rocks. Such samples are thus not ideal for testing all aspects of inter-grain interactions.

The only method that has been shown to control stoichiometry, grain size and spacing in the synthesis of magnetic minerals is electron beam lithography (EBL). Starting with a thin film of material, EBL is used to produce arrays of near-identical particles with accurately controlled spacing (figure 3). These samples are ideal for testing various theories and the contribution of magnetic interactions to palaeomagnetic experiments. However, production of EBL samples has proved to be exceptionally difficult, with only two separate projects successfully managing to make samples for palaeomagnetic investigation (King *et al.* 1996, Krása *et al.* 2009). The only mineral to be as yet successfully synthesized that is of interest to the geophysicist is magnetite.

These studies have shed much light on the behaviour of both isolated PSD grains, and interactions between such grains. They have shown that while interacting particle assemblages may have unfavourable rock magnetic parameters, e.g. from hysteresis, which are commonly used to discriminate between "reliable" and "unreliable" recorders, they are still able to retain palaeomagnetically meaningful palaeodirectional information (Krása *et al.* 2011).

Numerical modelling is a valuable technique for understanding the theoretical basis of palaeomagnetic data. Magnetic states of interacting assemblages and individual PSD and MD grains are determined by a complex interplay of nonlinear, short and long-range interactions, plus variations in temperature. For this reason, analytic theories have not been able to provide predictive models to determine the accuracy of palaeomagnetic recordings. Instead, numerical models that solve Brown's

4: A numerical 3D micromagnetic model of nine magnetite grains: (a) "Small-field interacting state" – the grains experience small interactions fields but the majority of grains are in a vortex state. (b) "High-field interacting state" – when the grains are touching, a "super-vortex" magnetic structure forms, causing all the grains to display more uniform magnetic structures than seen in (a). (Redrawn from Evans *et al.* 2006)

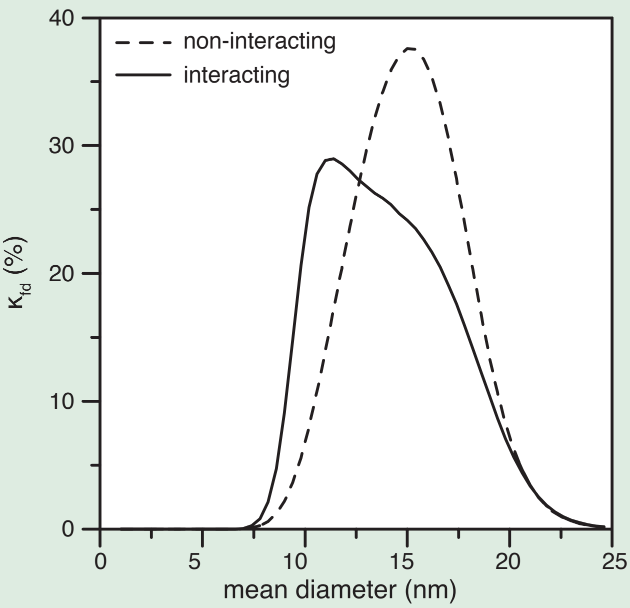


(1963) micromagnetic equations are employed to understand these complex systems theoretically. Over the past 25 years these models have yielded a wealth of insight into the magnetic structures and behaviour of non-uniform magnetic structures within crystals covering more than an order of magnitude in size, e.g. for magnetite cubo-octahedral grains of length 0.01 to 1 µm. For example, the vortex structures shown in figure 1 were first predicted by numerical models, before being observationally verified.

In the last ten years, these models have also been applied to the study of magnetic interactions in assemblages of SD and PSD grains (Muxworthy *et al.* 2003, Muxworthy and Williams 2005). They have shown some paradoxes: interacting SD grains become more multidomain-like in character, while interacting PSD grains can become more SD-like in character, by forming super-vortex structures (figure 4). These model predictions have been confirmed on the microscopic scale, and also in the bulk-magnetic parameters.

Currently numerical micromagnetic algorithms can only determine static magnetic interaction fields, as thermofluctuations have yet to be fully implemented in models for natural systems, though this line of development is currently active and thermally activated micromagnetic models should be working within the next year or two. This makes current and previous calculations for dynamic interactions reliant on assumptions in micromagnetic models, such as those used in the calculations presented in figure 9, or approximated theories like those of Dormann *et al.* (1988). As dynamic systems are in non-equilibrium they are unlikely to retain a palaeomagnetically meaningful magnetic remanence, but they can still contribute to the magnetic signature of sample; this is particularly important in environmental magnetic studies where the signature is often used as a proxy. Using a variation of the model described

5: Results of a numerical model for the frequency dependency of magnetic susceptibility (κ_{fd}) versus mean grain size for an assemblages of SD magnetite particles with a mixture of dynamic and static interactions. It is seen that the effect of weak interactions is to reduce κ_{fd}. (Redrawn from Muxworthy 2001)



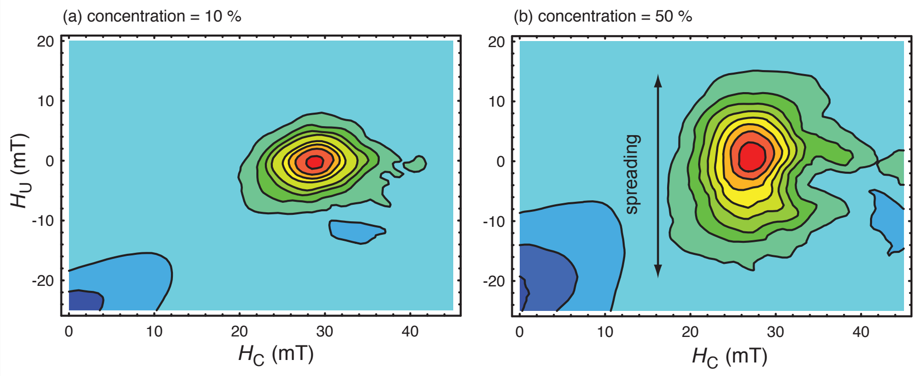
in Dormann *et al.* (1988), Muxworthy (2001) showed that in weakly interacting SD assemblages the role of dynamic magnetic interactions is to supress a very common environmental parameter referred to as the frequency dependency of magnetic susceptibility, κ_{fd} (figure 5). The effect of interactions is to reduce κ_{fd} in absolute value and move the peak to smaller grain sizes. This partially explains why large values of κ_{fd}, which are theoretically possible, are rarely seen in natural samples.

Magnetic interactions in rocks

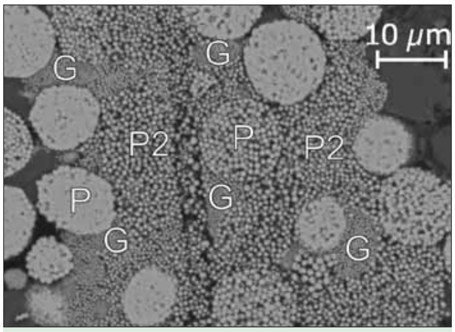
As it is not possible to examine every palaeomagnetic sample under the microscope, diagnostic bulk measurements that can identify the presence of magnetic interaction fields are required. There have been several approaches for assessing this, two of which are described below. However, differentiating between intergrain magnetostatic interactions and internal magnetic interactions between domains, i.e. multidomain behaviour, is particularly difficult as the magnetic responses of the two systems are often similar.

Traditionally, people have used Henkel plots (Henkel 1964) or its modern modification the deltaM curve, which are constructed from remanence acquisition curves for the same sample in two magnetic states (demagnetized and reversely magnetized). DeltaM plots work particularly well in the material science world, where synthetic samples have narrow grain size distributions of SD grains; however, natural systems rarely have such assemblages and these simple plots do not yield sufficient discriminatory usefulness when working with natural samples.

To better quantify the behaviour of natural systems, first-order reversal curves (FORC) measurements were developed in the late 1990s (Pike *et al.* 1999, Roberts *et al.* 2000), and have recently become common as the machines required to measure them have become readily available. FORC measurements map out the



6: Two numerically simulated FORC diagrams for assemblages of identical SD magnetite particles with cubic magnetocrystalline anisotropy. (a) The concentration of particles is 10% and (b) the concentration is 50%. Increasing the concentration increases the levels of inter-grain interactions resulting in spreading in the *y*-axis. As a first-approximation the *x*-axis is related to the coercivity (magnetic stability) distribution of the assemblage and the *y*-axis is a measure of magnetostatic interactions. (Redrawn from Muxworthy *et al.* 2004)



7: Back-scattered electron microscope images illustrating microtextures of authigenic greigite (G, Fe_3S_4) and pyrite (P, P2, FeS_2) in mudstone samples from New Zealand. Such samples' magnetic remanences were found to be unreliable and their FORC diagrams indicative of high levels of magnetic interactions. (From Rowan and Roberts 2006)

internal structure of a hysteresis loop, and provide a distribution of magnetic responses from a sample (figure 6). It has been shown that as a first-approximation, the *x*-axis represents the coercivity (magnetic stability) distribution of particles within a sample, and the *y*-axis is a measure of magnetostatic interactions (Muxworthy and Williams 2005).

The FORC method in itself does not distinguish between internal interactions, i.e. multidomain behaviour, and inter-grain interactions: both cause spreading in the vertical axis; however, experience of handling natural magnetic systems tells us that usually the position of the peak of the distribution for MD grains lies near to the *y*-axis origin, and that of SD grains and PSD grains a little further from the vertical axis origin. Distributions with large spreads in the *y*-axis, where the peak of the distribution is far from the *y*-axis, are indicative of interacting SD grains (Muxworthy *et al.* 2004).

Combining theory and experiment

Neither numerical nor experimental approaches are able to answer uniquely the contribution of magnetic interactions to the palaeomagnetic signal, but a holistic approach can tell us where strong magnetic interactions are present. On a practical level such a holistic approach will involve a combination of scanning electron microscope (SEM) analysis including analytical analysis, and thorough mineral magnetic analysis using FORC diagrams in combination with thermomagnetic measurements. For example, such an approach was used successfully in the study of mudstones from New Zealand (Rowan and Roberts 2006), whose palaeomagnetic signal in some strata was dominated by interacting, authigenic iron sulphides (greigite, Fe_3S_4) (figure 7). The greigite-dominated signals were found to be unreliable. Once the results from such samples had been removed from the data set, the tectonic interpretation of the palaeomagnetic study could be made successfully (Rowan and Roberts 2006).

Magnetic interactions for navigation

Magnetotactic bacteria produce chains of magnetic crystals (magnetosomes) that usually consist of magnetite (Fe_3O_4) or greigite (figure 8). These magnetosome chains are found in both unicellular bacteria and in larger multicellular magnetotactic prokaryotes (MMP) (Faivre and Schüler 2008). The primary purpose of magnetosomes is thought to be navigation (magnetotaxis), therefore natural selection should ensure that magnetosomes provide a strong magnetic signal to maximize their efficiency (Kopp and Kirschvink 2008). The magnetic state that best exhibits this quality is the stable SD state. To maximize the magnetic signal from a magnetosome, the magnetosome should be just below or at the critical SD to PSD/MD grain size threshold. The exact threshold is dependent on many factors such as grain morphology. Determining the critical stable SD size range as a function of morphology is important for determining magnetosome function and possible magnetotaxis efficiency.

It is common to assess the domain state of magnetosome crystals by plotting their length versus grain-elongation axial-ratio (AR; short-axis/long-axis or width/length) on domain state phase diagrams (Thomas-Keprta *et al.* 2000), initially determined analytically by Evans and McElhinny (1969). They calculated the SP to stable SD critical size and the SD to PSD/MD critical size as functions of AR for individual particles of magnetite. Subsequently, both the SP to stable SD transition size (Winklhofer *et al.* 1997, Muxworthy and Williams 2009) and the SD to MD transition size (Fabian *et al.* 1996, Witt *et al.* 2005, Muxworthy and Williams 2006) have been re-examined and revised for individual magnetite particles through application of the numerical micromagnetics.

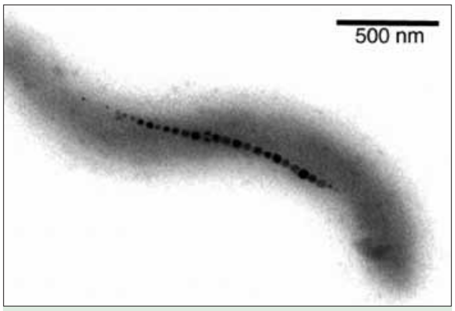
Muxworthy and Williams (2006) argued that it is flawed to compare magnetosome sizes with critical grain size boundaries derived for individual crystals because magnetosomes very often occur in magnetostatically interacting chains (Faivre and Schüler 2008). Muxworthy and Williams (2006, 2009) performed calculations for the critical thresholds for magnetically interacting magnetite rectangular cuboids, and demonstrated that for cube-shaped grains, interactions within chains increases the stable SD to MD threshold size for magnetite from ~70 nm to a maximum of ~200 nm (figure 9).

Interactions also decrease the SP/SD size for cube-shaped magnetite grains from ~26 nm to a minimum of ~12 nm for a thermal relaxation time of 60 s. Muxworthy and Williams (2006, 2009) showed that magnetostatic interaction fields are sufficient to cause the largest observed magnetite magnetosome crystals found in living bacteria (length = 250 nm [AR = 0.84]; Lins *et al.* 2005) to be in a stable SD state; without magnetostatic interactions they would be in a MD state and would have a far lower magnetotaxis efficiency.

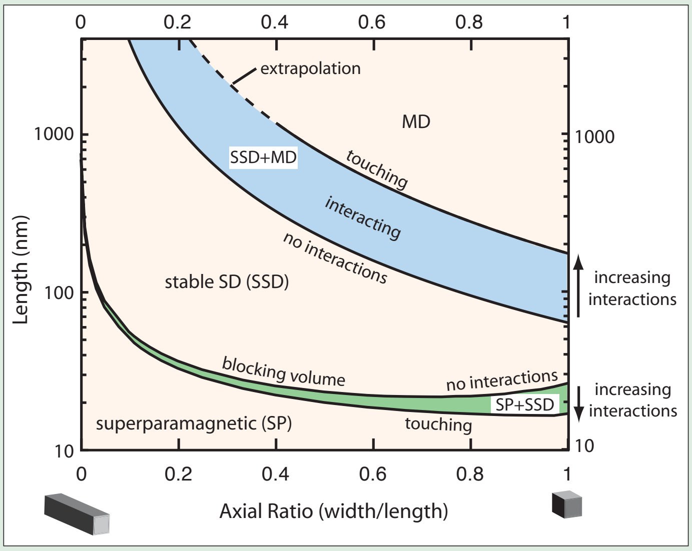
Magnetofossils and early life

When magnetotactic bacteria decease, they are one of the few bacteria that regularly leave an inorganic trace of their existence; the chains of magnetosomes often remain partially intact and are referred to as magnetofossils. Magnetofossils have been identified in pre-Cambrian rocks ~2 Ga in age (Chang *et al.* 1989), and have been suggested as evidence for extraterrestrial life (Friedmann *et al.* 2001).

One of the criteria for identifying magnetic crystals as magnetofossils is the presence of complete or partially broken chains. It is assumed that the magnetofossils were used for magnetotaxis, for which we assume that the magnetic crystals were in a SD state. Examining martian meteorite ALH84001, Friedmann



8: Transmission electron micrograph of an unstained cell of *Magnetospirillum magnetotacticum*, showing chain of magnetite magnetosomes. (From Bazylinski and Frankel 2003)



9: Stable single-domain ranges for individual grains and chains of interacting magnetosome crystals. Using the format of Evans and McElhinny (1969), length (long-axis) rather than volume is plotted versus AR for various grain spacing/length ratios. The figure considers the effects of interactions in chains on the stable SD range: interactions cause the SD-to-SP boundary to decrease and the SD-to-MD boundary to increase. The use of the length makes for easier comparison with Evans and McElhinny (1969), but the figure is a little more complicated to understand because on moving horizontally across the figure the volume of the grains changes, i.e. there is a change both in shape and volume contributing to the critical boundaries. (Modified from Muxworthy and Williams 2009)

et al. (2001) identified chains of magnetite, which they postulated may be magnetofossils of former magnetotatic bacteria; however, reconstructing the chains of magnetite using micromagnetic models (Muxworthy and Williams 2006) clearly demonstrated that the magnetic interactions between grains were insufficient to push the magnetic crystals into the SD stability field. The magnetic crystals were in MD states, making it unlikely that they are the remnants of magnetosomes used for magnetotaxis in an early martian magnetic field.

Conclusions

In rocks and other environmental samples, the contribution of magnetic interactions to the magnetic signals is generally thought to be undesirable; however, magnetic interactions appear to affect some magnetic remanences more than others. For example, thermoremanences acquired by igneous rocks during cooling the Earth's magnetic field, appear to be less effected by interactions than a chemical remanent magnetization carried in sedimentary rock dominated by authigenic minerals. It is, therefore, important to consider the type of magnetic remanence being carried by a rock, when estimating the degree of magnetic interactions in it. It is also important to consider the type of information that is being recovered. Generally, directional data is less affected by magnetic interactions than palaeointensity data (the recovery of the ancient field intensity).

There are clear cases in Nature where the role of magnetic interactions is beneficial. In particular in magnetotactic bacteria, that have been shown to have optimal magnetosome morphology and inter-grain magnetic interactions to maximize magnetotaxis. Their remains (magnetofossils) have been used to identify early life, and are excellent recorders of the geomagnetic field, as the highly interacting chains paradoxically individually behave like "ideal non-interacting" grains.

What areas of magnetic interactions are still to be truly understood? Magnetically interacting systems are highly nonlinear so every case is unique, but there are several key areas of research were the contribution of magnetic interactions is poorly understood. First, the role of magnetic interactions during thermoremanence acquisition has yet to be fully understood. There have been experimental and numerical attempts to quantify the contribution of interaction to thermoremanence acquisition, but as yet the results are not entirely conclusive. Second, relating the interaction fields observed with electron microscopes or calculated in numerical models to bulk magnetic parameters. In the first two cases, the number of crystals examined is of the order of 10 to 100 particles, whereas bulk measurements are made on potentially millions of particles. To resolve this gap, there are two possible solution paths: increase numerical model size through a combination of increased CPU power and quicker algorithms; and test the models on ideal samples such as those produced by EBL, which can be examined under a microscope, modelled and magnetically measured like a bulk sample. ●

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Wallace Leslie William Sargent FRS
1935–2012

Fellow, Honorary Fellow and George Darwin Lecturer of the RAS, innovative spectroscopist.

Wallace Sargent made striking advances in astronomy using spectroscopy with the world's largest telescopes to great effect. He showed that very low metal abundances were not accompanied by very little helium, but there was a floor to helium abundances of about 24% by mass. This confirmed a prediction based on helium synthesis in the hot Big Bang. With Searle he showed that the peculiarities of the abundances of the "peculiar A stars" were very precisely related to the atmospheric temperatures and gravities of those stars. Thus he laid the foundation on which his student Michaud explained the peculiar abundances via the floating of elements with strong spectral lines on the blast of radiation coming from stars whose atmospheres were not mixed by convection.

Initially using Boksenberg's photon counting detector with the 200 inch Hale telescope at Palomar Observatory, and later with the even larger Keck telescope on Hawaii, he studied the distribution of absorption line systems due to intervening clouds on the lines of sight to distant quasars. The Sargent–Boksenberg partnership laid the foundations of this field by carrying out the first statistically rigorous surveys of quasar absorption systems. Among other discoveries, their work proved conclusively that quasar redshifts are cosmological. Sargent and collaborators also used the statistics of quasar absorption systems to show that a significant fraction of the baryons in the universe were once in the intergalactic medium traced by such clouds.

He looked for evidence of supermassive black holes in the giant galaxy M87 in Virgo and in the nuclei of other galaxies, but though his results were indeed correct, they did not provide unequivocal evidence. Clear evidence only emerged in 1995 when very-long-baseline radio interferometry of super-masers in the galaxy NGC 4258 demonstrated a central dark mass of 400 million times the mass of the Sun.

His father was a gardener in Lincolnshire and the house had very few books, but Wal taught himself to read via comic strips. His mother felt education was important. He was the first member of his family and of his school to go to university. At Manchester University he studied physics and stayed on to do research in astronomy under Profs Zdenek Kopal and Franz Kahn, who became his supervisor. As a postdoc he joined Prof. Greenstein's observational project at Caltech on the abundances of the elements in stars. He was captivated by what could be discovered via spectroscopy. His first real discovery was the amazing result that the helium in the atmosphere of the binary star 3 Centauri A was more than 80% in the rare isotope ^{3}He and not in the much commoner ^{4}He. He and Jugaku had measured the wavelengths of the lines to high accuracy and the pattern by which they lay off the wavelengths of the ^{4}He lines matched precisely that caused by the isotopic shifts.

"His father was a gardener and the house had very few books, but Wal taught himself to read via comic strips"

Royal Greenwich Observatory

In 1961, Wal returned to the UK for three years at the Royal Greenwich Observatory, at Herstmonceux. There he met Anniela Cassells, who became his wife and later a strong force in infrared and millimetre astronomy in her own right. They returned to the USA, joining Margaret and Geoffrey Burbidge at the University of California, San Diego. Wal, Peter Goldreich and John Bahcall aimed to be at the same university, but when John was asked to join them at UCSD, he replied that Caltech was better. Both Wal and Peter later moved to Caltech but they were not there long before John Bahcall, who had found multiple absorption-line redshifts in quasars, was appointed to lead astronomy at the Institute of Advanced Study in Princeton.

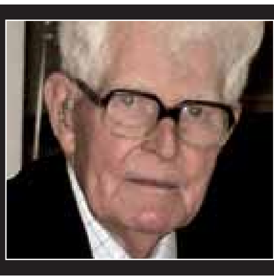
Wal remained at Caltech, becoming full professor in 1971 and Ira S Bowen Professor in 1981. That year he was elected a fellow of the Royal Society and in 2005, having finally become a joint US citizen, he was elected to the US National Academy of Sciences. Earlier he was a Sloan Fellow and was awarded the Warner and Heinemann Prizes. He was the Bruce medallist of the ASP in 1994 and Russell Lecturer of the AAS in 2001. He gave the Royal Astronomical Society's George Darwin Lecture in 1987, entitled "Observing the evolution of large scale structure in the universe", and was made an Associate (now Honorary Fellow) of the Society. In 2011 he was awarded the IAP medal of the Institut d'Astrophysique, Paris. He served as Caltech's executive officer in astronomy for 1975–81 and 1996–7. He was director of the Palomar Observatory for 1997–2000. Many of his past graduate students now hold major positions in US universities and observatories. The late John Huchra, professor at Harvard, who made major redshift and infrared surveys of the universe, was one of them.

Wal had an endearingly irreverent sense of humour and keen interests in sport and music. He admired original outsiders and became a friend of Fritz Zwicky, who had joined Caltech before it had a department of astronomy. It was by studying some of Zwicky's small but gas-rich galaxies that he and Searle had established the floor to helium abundances. When Zwicky retired, Wal took over responsibility for the continuance of the Palomar supernova search. He also ran the second epoch Palomar Sky Survey with the 48 inch Schmidt telescope, which was improved by a new Grubb–Parsons achromatic corrector plate.

Wal is survived by his wife Anniela, who is of Scottish descent and also became a professor of astronomy at Caltech, director of its Owens Valley Radio Observatory, and is currently vice-president for student affairs. They have two daughters.

Donald Lynden-Bell and Max Pettini

C Andrew Murray
1926–2012



Fellow of the RAS, distinguished astrometer.

I first met Andrew Murray in the 1970s when I visited the Royal Greenwich Observatory (RGO) as a doctoral student and he and George Wilkins helped me with the calculation of some 17th-century lunar and planetary positions. We became friends and found that we shared several interests and loyalties: to historical astrometry, to Oxford and to the Church of England. Andrew was an astrometer throughout the whole of his professional career in astronomy, between 1949 and 1986.

Andrew was born in Eastbourne in 1926, the son of an architect. He went in 1939 to Westminster School, which was about to be evacuated to the safety of Hertfordshire. In 1944 he won an exhibition to Christ Church, Oxford, to read mathematics, after which he served in Egypt in the Army Education Corps. Andrew was always amused by the fact that he entered professional astronomy via the Labour Exchange. Looking for a mathematically related job upon leaving the Army in 1949, he was directed towards a temporary assistant experimental officership at the Royal Observatory, then on Greenwich Hill. This would lay the foundation for his distinguished career as an astronomer. Andrew often lamented, however, that his academic training as a mathematician obliged him to learn his physics on the hoof, at Greenwich. Geometry was really his passion, and this made him ideally suited to practise the most ancient branch of astronomy: astrometry.

At Greenwich, Andrew cut his teeth in astrometry by doing meridian work with the 100-year-old Airy Transit Circle, which *still* defines the International Greenwich Meridian. Meridian work had been the bedrock of Greenwich astronomy, going back to Flamsteed in 1675. Andrew gave me detailed accounts of how the Transit Circle was used, corrected, and its results analysed, as well as demonstrating it to me, with Gilbert Satterthwaite, in 1996. I also recall him telling me about the dirty air of Greenwich in the early 1950s, for when you covered your desk with a white sheet before going home, it would be speckled with carbon particles next morning. It is hardly surprising that Andrew played a significant part in establishing the Greenwich–Herstmonceux meridian difference after the Royal Observatory's move to the cleaner air of Sussex in 1954.

Modern astrometry

In many respects, Andrew Murray's RGO career presents a history of astrometric advancement across four decades: from Airy's Transit Circle and the Cooke Reversible Transit Circle, to Hipparcos and beyond. Indeed, in an unpublished autobiographical memoir kindly sent to me by his widow Mary, one can trace the progress of modern astrometry as it moved from manual to electrical, photographic and on to digital technologies. A branch of astronomy, moreover, which would come to play a vital role in a diversity of fields, such as timekeeping, geodesy, spacecraft navigation, optical and radio cosmology, and in the exact visual identification of pulsars.

In 1960 Andrew left the Meridian Department to work in RGO astrometry. Data reduction, or the obtaining of useful information from raw observations, was always a problem, for one could make observations quicker than one could "reduce" the data, especially photographic data. After 1965 he came to work with the new electronic GALAXY machine to measure 6000 astrometric plates, along with working on the early development of the European Space Agency's Hipparcos astrometric satellite, launched in 1989. Indeed, these were enterprises replete with complex geometrical problems of a kind to which Andrew was naturally drawn.

Andrew travelled widely in the cause of astrometry. He played an important role in the setting up of Denmark's ground-breaking Carlsberg Automatic Meridian Circle at La Palma in the 1970s, as well in new centres of astrometric excellence in the USA, Australia, Russia, Finland and elsewhere. Andrew Murray became a world authority on astrometry and the development of refined angle-measuring and reduction techniques. I remember attending his "standing room only" Halley Lecture at Oxford on "The distances to the stars" in May 1988. And his *Vectorial Astronomy* (1983) provided a classic statement on modern astrometry.

Andrew was also involved in the commissioning of the Sir Isaac Newton 98 inch telescope at Hertmonceux, formally inaugurated by HM The Queen in1967, and soon after he described and demonstrated the prime focus arrangement of the telescope on the BBC's *Blue Peter* children's television programme.

Although observatory research can often be isolating work, astronomers as a breed tend to be convivial, and Andrew was certainly good company. He made and retained numerous friends across five continents. He probably began to acquire his circle of astronomical friends in 1952, when he became a Fellow of the RAS, and it expanded further upon his election to the RAS Dining Club in 1970. As well as friends, Andrew had powerful loyalties to institutions, most notably Christ Church, Oxford, and I used to enjoy meeting Andrew and Mary when they were up in Oxford for college events.

Andrew Murray married Mary (née Nason), daughter of the Vicar of St Alphege's Church, Greenwich, in 1954 and they had three children, Simon, Jane and Richard. Andrew and Mary were wonderful hosts at their house in Eastbourne. I am indebted to him for many insights into the modern history of British astronomy.

Andrew Murray had been ill for some time, but died suddenly and rather unexpectedly at home, on 7 November 2012. Rest in peace.

Allan Chapman

DEATHS OF FELLOWS

Prof. Charles M Fehrenbach
Born: 29 April 1914
Hon. Fellow: 10 February 1961
Died: 9 January 2008

Emeritus Prof. Yoshio Fujita
Born: 28 September 1908
Fellow: 9 December 1955
Died: 9 January 2013

Dr John A Galt
Born: 8 March 1925
Fellow: 8 January 1971
Died: 26 December 2012

Prof. Masatoshi Kitamura
Born: 10 January 1926
Fellow: 13 April 1962
Died: July 2012

Dr John V Major
Born: 3 February 1929
Fellow: 8 March 1985
Died: July 2012

Sir Patrick C A Moore CBE FRS
Born: 4 March 1923
Fellow: 14 October 1949
Died: 9 December 2012

Dr David Orr
Born: 18 March 1935
Fellow: 13 April 1973
Died: 19 December 2012

Prof. Raghavaiyengar Parthasarathy
Born: 24 June 1929
Fellow: 11 November 1960
Died: 7 March 2012

Stephen D Price
Born: 3 August 1941
Fellow: 8 April 1998
Died: 1 December 2012

Prof. Archibald E Roy
Born: 24 June 1924
Fellow: 9 February 1951
Died: 27 December 2012

Prof. Jorge Sahade
Born: 23 February 1915
Hon. Fellow: 13 February 1970
Died: 18 December 2012

Archibald Edmiston Roy 1924–2012

Fellow of the RAS, known for work in celestial mechanics, a prolific and renowned writer.

Prof. Archie E Roy died suddenly on 27 December 2012 in Drumchapel Hospital, Glasgow. Archie was born in Clydebank, West Dunbartonshire, where his father was a draughtsman at John Brown's shipyard, and was brought up in a household where reading and education was the norm. He was left-handed but this bias was "discouraged". As a result, he was able to draw matching celestial spheres simultaneously with both hands and write across the full width of a blackboard, transferring the chalk from one hand to the other at the mid-point, much to the astonishment of his students.

After attending Hillhead High School, he registered as a student at Glasgow University in 1941, intending to become an architect, but he contracted tuberculosis and spent three years in a sanatorium. He continued his education by reading avidly, developing an interest in astronomy. He eventually returned to the university and was awarded a BSc (Hons) in Natural Philosophy and Astronomy in 1950. With Prof.Peter A Sweet as his supervisor, he obtained a PhD in 1954 for work on the meridional circulation within stars, with all the myriad numerical calculations performed by hand using a desk mechanical calculator. He then taught at Shawlands Academy in Glasgow until 1958. He became interested in the activities of the British Interplanetary Society and was key to the development of the Scottish Branch in the early 1950s.

On 1 April 1958 he was appointed as lecturer in the Glasgow University Department of Astronomy. In the summer of that year he set up a team at the university observatory to participate in Project Moonwatch, associated with the International Geophysical Year; the scheme involved the spotting and tracking of satellites before the establishment of professional stations. More than 100 satellite passes were recorded in three years.

His passion for celestial mechanics developed through a study of luni-solar perturbations of Earth satellites. As electronic computers developed, he undertook grander studies, including one related to long-term commensurabilities in the solar system. He became the international team leader for Project LONGSTOP (the LONg-term Gravitational STudy of the Outer Planets), which used numerical and analytical methods to investigate the stability of the outer planets over an interval of 10^8 years, a time span approaching the known age of the system. A second major contribution to astrodynamics was his work on four-body resonances, referred to as the Caledonian Problem, resulting in the only known analytical solution for four-body problems of finite mass. This project was conducted with Bonnie Steves, who now continues the work at Glasgow Caledonian University.

Author and speaker

His classical text, *The Foundations of Astrodynamics*, was published in 1965 and later republished as *Orbital Motion*, now in its fourth edition. Archie is well-remembered as an inspirational speaker and a respected leader in the field. His international reputation led to his role as director of NATO Advanced Study Institutes in Cortina and Maratea, Italy, l987, l990, 1993 and 1997. He supervised 20 PhD students and acted as second supervisor for two others. To commemorate his contributions to celestial mechanics, asteroid no. 5806 was named Archieroy in his honour.

For general teaching of astronomy, he produced two texts in collaboration with David Clarke in 1977, *Astronomy: Principles & Practice* and *Astronomy: Structure of the Universe*. Both became standard undergraduate teaching material, reprinted and extended to three editions; the first book of the pair was revised in a fourth edition in 2003. Concurrently he was promoted, becoming titular professor in 1977. Archie enjoyed presenting educational courses and talks to wide audiences and holds the record of supporting the university's Adult Education Department for over 50 years.

On joining the Glasgow staff in 1958, he developed a strong friendship with Michael W Ovenden and ideas on many issues bounced between them. One of Ovenden's interests was an investigation of the origin of the constellations. Archie later developed the theme – known as "The Lamps of Atlantis" – into a popular and much-requested lecture. Archie was also fascinated by the principles whereby the brain stores and recalls information, and wrote several papers on the topic in biological journals. He and Ovenden worked together on the problem of disseminated storage of information and sequential coding and on understanding of memory processes within living brains.

Inspired by Alexander Thom's work on megalithic sites, Archie also became fascinated by stone alignments and their connections with the calendar and astronomy, and wrote several papers on these topics. In particular, summer holidays were spent investigating the Machrie Moor sites on the Isle of Arran, with some success in finding "missing" stones.

Archie's interest in the paranormal and the possibility of "the after life" were undertaken from a scientific standpoint. He investigated many local "paranormal" events, for which he became known as the Glasgow Ghostbuster, and he founded the Scottish Society for Psychical Research in 1987. His involvement with "peculiar" stories and events provided him with evidence of patterns of behaviour which he described in *A Sense of Something Strange* (1990) and *Archives of the Mind* (1996). He was awarded the Myers Memorial Medal in 2004 by the Society for Psychical Research. In 1968 Archie made a foray into fiction by writing *Deadlight*, which was received with critical acclaim. Five successful novels followed.

Archie Roy acted as head of the Department of Astronomy from 1982 until 1986 when the new Department of Physics and Astronomy formed. He retired in September 1989, and the occasion was marked by a day of special lectures entitled "A lad o' pairts", with invited speakers covering his interests from archaeo-astronomy to celestial mechanics, and from the paranormal to science fiction.

Archie combined his distinguished professional career with wider interests, exemplified by his successful bet on the date of the first Moon landing – made before the Apollo programme and honoured by William Hill to the tune of £1200 – and his spontaneous performance of Bach's *Toccata and Fugue in D Minor* on James Watts's organ in the People's Palace museum in Glasgow. Archie had a genuine interest in so many areas which he followed with a childlike enthusiasm. If he had to accept any accolade in respect to his life, he would modestly wish to be referred to simply as "a teacher".

He is survived by his wife Frances, his three sons, Archie (Jnr), Ian and David, and two grandchildren, David and Fraser.

David Clarke

Library offers spare journals

The RAS Library is to dispose of some duplicate and low-usage journal titles and would like to offer them first to Fellows for their own use or for their institution.

The RAS Library annexe is a large room above the neighbouring Geological Society, mainly stocked with seldom-used journals and a reserve stock of old books. The Librarian and the Chairman of the Library Committee have agreed with the Executive Secretary and Council that some journals – those which are duplicate sets, easily available elsewhere or peripheral to the purpose of the RAS and its historic collections – can be removed from the catalogue and disposed of. We are only at the beginning of a lengthy process, but have decided as a matter of urgency that some space must be freed up.

If Fellows wish to avail themselves (or their departments or universities) of this offer, then we suggest that a charitable donation should be made to the Society to reflect the value (which can be nominal) that the Fellow chooses. The duplicate RAS titles are as follows:

- *Astronomy & Geophysics* (miscellaneous copies, unbound)
- *Geophysical Journal of the RAS* and *Geophysical Journal International* (1970 to present, unbound)
- *Memoirs of the RAS* (miscellaneous copies, unbound)
- *Monthly Notices of the RAS* (1970 to present, unbound)
- *Quarterly Journal of the RAS* (1960–1996, unbound)

Separate bound sets of all these RAS journals are already available in the main library and will, of course, be retained.

Other titles are:

- *Applied Optics* (1962–1996, 1999–2000, 2002–2005, bound)
- *Les Comptes Rendus de l'Académie des sciences…* (1840–1980, bound but many in poor condition)
- *Yearbook of the Royal Society (London)* (1896–2005, bound)

If anyone is interested in any of these journals – either the full sets or parts thereof – or would like further information on the journals available, please contact the Librarian, Jenny Higham, by 30 April 2013. Note that Fellows will need to arrange collection.

http://bit.ly/YLq7IP

Register now for NAM2013

The National Astronomy Meeting for 2013 will be held at the University of St Andrews from 1–5 July and registration is now open.

NAM is the UK's largest general astronomy conference and is sponsored by the Science and Technology Facilities Council. You are encouraged to register online, where you can also find details of the scientific and social programme and accommodation. There is a limited amount of university accommodation available on a first come, first served basis, and the website has links to other accommodation in the town.

More information will be added to the site as time goes on, but if you have questions for the organizers, email NAM2013@mcs.st-and.ac.uk.

http://www.nam2013.co.uk

News in Brief

Patrick Moore Medal

As the end of the school year comes into sight, Fellows are asked to consider possible nominees for the RAS's Patrick Moore Medal. This medal was awarded for the first time in 2012 and is for secondary level teachers who have made an outstanding contribution to the teaching of astronomy or geophysics. The deadline for nomination is in the autumn, so think ahead!

http://bit.ly/15xndvp

Legacies to the RAS

RAS funds to support research fellowships, awards and meetings are supported by donations and bequests from Fellows. If you are considering a legacy, the RAS Treasurer Prof. MIke Cruise would be happy to discuss your wishes. The Society wants to be sure that any bequest can be used in the way that the Fellow wishes, and that the generosity of such a bequest can be recognized.

http://bit.ly/Zblk5o

New Fellows

The following were put forward for election as Fellows of the Society on 8 February 2013:

Margaret Anthony, London.
David Bekaert, University of Leeds.
Dr Elmé Breedt, University of Warwick.
Michael Czajkowski, Lincolnshire.
Thavisha-Erandinie Dharmawardena, London.
Emma Fegan, Abingdon.
Robert Firth, University of Southampton.
Andrew Gillaspy, Lewes.
Gareth Griffiths, Bristol.
Richard Harrison, Liverpool John Moores University.
Paul Hattle, Winchester.
Mark Hoggard, Cambridge.
Rebecca Keoghan, London.
Elisa Kraus, St Leonards on Sea.
Arrow Lee, MSSL.
Tamara Leitan, Henley-On-Thames.
Joshua Lovell, Cambridge.
Ian McDowell, London.
Jessica Mowatt, Gwynedd.
Carla Natário, St Albans.
Eamon O'Gorman, Co. Kilkenny.
Jennifer O'Hara, University of St Andrews.
Michael Parker, University of Cambridge.
Becky Parker, Canterbury.
Natalia Pascual, CESPAR, The Open University.
Agnieszka Pollo, National Centre for Nuclear Research, Warsaw.
Wil Poole, MSSL.
Dr David Salmon, Didcot.
Dr Susanne Schwenzer, The Open University.
Darryl Sergison, Cornwall.
Hari Sriskantha, The University of Edinburgh.
Prof. Graham Stuart, University of Leeds.
Alireza Tabatabaei, London.
Adam Torry, Powys.
Joseph Walmswell, University of Cambridge.
Anne Wellbrock, MSSL.
Dr Paul Withers, Boston University, USA.
Dr Penelope Wozniakiewicz, University of Kent.

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